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Edited by

O. M. B. BULMAN and S. R. NOCKOLDS

assisted by

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GEOLOGICAL MAGAZINE

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Scourie Dykes and Laxfordian Metamorphism

By E. B. BAILEY

ABSTRACT

A review is offered of some of the conclusions reached by Teall and his Survey colleagues on the Lewisian Complex of the North-West Highlands, especially such as have been strengthened by recent work by Sutton and Watson. In other directions support is given to Peach and Gunn's view that the Loch Maree sediments are later than the Scourie Dykes and not, as Clough tentatively suggested, intruded by sills fed from these dykes; also new hypotheses are advanced concerning Laxfordian folding of the Scourie Dykes at Loch Maree, and Caledonian thrusting of Assynt type of Lewisian over Laxford type at Durness.

GEOGRAPHY

Localities named in text on or near west coast of Scotland. Sheet 113, etc., are sheets of Geological Survey 1 in. map. Intervening distances are measured in miles from north to south.

Cape Wrath (Sh. 113), Durness, and Eribol (Sh. 114), *on N. coast*—16 m.—Loch Laxford (Shs. 113, 107)—3 m.—Scourie (Sh. 107)—8 m.—Loch Glencoul (Sh. 107)—4 m.—Loch Assynt (Sh. 107)—23 m., mostly in Sh. 101—Loch Broom, and Gruinard Bay (Shs. 101, 92)—7 m.—Poolewe (Sh. 91)—4 m.—Gairloch, and Loch Kerry (Sh. 91)—2 m.—Letterewe on Loch Maree (Sh. 92)—10 m.—Loch Torridon (Sh. 81)—2 m.—Rona, and Raasay, *islands E. of Skye* (Sh. 81).

INTRODUCTION

AT the February meeting of the Geological Society, 1950, J. Sutton and J. Watson delivered three closely related papers dealing synthetically with the North-West Highland districts of Loch Torridon and Loch Laxford. Proofs of abstracts, circulated in advance, furnished a competent résumé of what had long been published on the subject. There was scarcely a new idea, but strange to say there was no allusion to any previous worker. Accordingly I sent a written contribution to the discussion, pointing out as kindly as I could that "like the authors of these summaries, I agree with the bulk of the striking results set out by Teall and his colleagues in the Geological Survey Memoir of 1907".

When a copy of the *Proceedings* arrived I found that the papers had evoked unusual interest, and that the President and nine other Fellows had taken part in the discussion. The authors' professor, H. H. Read, surprised me most. He referred warmly to his predecessors

on the Geological Survey, but it was clear that he had only a very vague idea of what they had accomplished. According to him " in this new attack was seen emerging a new concept ". In fact, " it seemed that the whole climate of Highland geology had suddenly become different." He further congratulated the authors on going into ground " where the whole study was dominated by the authority of the 1907 Memoir ", but where " their study had revealed unexpected vistas of profound significance that had embellished and adorned the Survey classic. That great man Teall ", he concluded, " foresaw to-day and he would have rejoiced to see it."

In trying to understand the above it must be remembered that Read did not join the Survey until 1914, by which time most of the Norwesters had retired. Moreover, Read was one of the first to leave for service in the 1914–18 war and since his return has been a very busy man. He cannot have failed to have gathered something from what has been published on the North-West Highlands; but probably in the course of years he has come to regard most of this knowledge as a product of his own meditations, awaiting incarnation by students from his laboratory.

In the first number of the *Geological Magazine* for this year Sutton and Watson have returned to the subject, and to all appearances they accept Read's estimate of the originality of their discoveries. We are told: " The series of dolerite dykes of the North-West Highlands has been described by Teall and others (1885, 1907). Recent work has shown that the dykes were intruded into an Archaean metamorphic complex (the Scourian complex), and that they underwent regional metamorphism during a later Pre-Torridonian epoch which has been called the Laxfordian period " (1951, p. 26).

Before going further with what many will think an ungenerous grumble I want to say that in my opinion the two authors are doing very useful work, and that its continuance is bound to bring welcome enlightenment. To help me with the following note I turned back to a manuscript which Kennedy and I have been preparing on the North-West Highlands for several years past. Its *History of Research* starts with what seems an apposite sentence: " In the course of our work we have found that almost every fact we observe has already been observed by someone else; and that almost every idea we explore has already been considered."

Teall and his Colleagues

The field-session of the Geological Survey, which immortalized the North-West Highlands, extended from 1883 to 1897. Even in regard to the Lewisian Complex it established structural and metamorphic results of outstanding importance. (The North-West Highland Memoir

uses the term Lewisian Gneiss as a loose cover for all local pre-Torridonian rocks regardless of character, cf. p. 33 ; Teall protested, cf. p. 41, and Lewisian Complex has since been commonly employed.)

The first great interpretative step was taken by Teall in 1883 (he joined the Survey staff subsequently in 1888). Introduced by Lapworth at Eribol to mylonization in relation to Caledonian movements, he went some 20 miles south-west to Scourie, situated in the foreland beyond the range of this group of disturbances. Here he took two specimens from what has since become the type Scourie Dyke. By happy accident one of these specimens proved on slicing to be a dolerite, the other a hornblende-schist (Teall, 1918, p. 3). This led on naturally through the years to discovery after discovery. Teall was a man readily moved to enthusiasm. I have been told that his old master, Bonney, had on occasion to remind him that the world is only partly made of Scourie Dykes.

Here an explanation may be offered in regard to the use of the term " Scourie Dykes ". As a rule this abbreviation has been relegated to conversation during the past sixty odd years. In print phrases such as " dykes like the Scourie dyke of Sutherland " have more usually been employed. There are, however, half a dozen cases where " Scourie Dykes " has escaped the general tendency to make printed titles self-explanatory. Good examples may be traced through the indexes of the Geological Survey memoirs on Glenelg (Sheet 71, 1910) and Central Ross-shire (Sheet 82, 1913). See also the North-West Highland Memoir (1907, pp. 107, 119) and MacGregor (1931, p. 528). The only matter in any doubt is whether " Scourie Dykes " should be restricted to basic representatives (N.W. Mem., pp. 89–98, etc.) or should also include ultrabasic (N.W. Mem., pp. 85–9, etc.) and intermediate (N.W. Mem., pp. 98–9, etc.) associates. The basic representatives are extremely numerous, and characteristically run W.N.W. The ultrabasic are exceptional. In the Assynt district they run east–west and cut their basic neighbours. The intermediate are comparatively inconspicuous. For my own part I group them all as " Scourie Dykes ", typical or otherwise.

Slices[1] of ultrabasic and basic dykes will be quoted in the sequel. Intermediate examples from 1 in. Map-sheet 107 include (2731–4, 3863, 3958–9, 4244). To these we may add an acid segregation from Sheet 101 (3905–6, 4692), described by Peach and Teall (N.W. Mem., pp. 96, 162) from a normal Scourie Dyke (3908, 4693 both enstatite-dolerite, 3907 massive epidiorite). Somewhat similar quartzose specimens (2933, 3040–1) come from one or two normal Scourie Dykes in Sheet 107 and have been incidentally mentioned by Teall (N.W. Mem., p. 93).

[1] Thanks to the Director I have been able to examine all slices in the Survey collection. Teall and colleagues have already published many references to individual slices, but experience has taught me that these can be usefully supplemented. I hope the lists given, though necessarily imperfect, may help others working in the same field.

The Geological Survey has recognized in addition a great set of microcline-rich granite-gneisses and pegmatites, forming "sills and dykes" well displayed north of Laxford—which no one has ever thought of grouping with the Scourie Dykes (cf. N.W. Mem., pp. 120–3). These intrusions, unlike the Scourie Dykes, do not have hypabyssal crystallization (they are not porphyries or felsites) and do not chill against country-rock.

Slices probably referable to granite members of the Laxford suite are: Sheet 107 (1818, 3423, 3477, 6283–8, 6292); Sheet 113 (2358, 2361, 2385, 32883); and to corresponding pegmatites: Sheet 107 (1819, 6289, 6290, 6326–7, 18803–6); Sheet 113 (874–5, 18791–6, 18802).

I confess that I used to feel a little uneasy in reading about the chilled edges of Scourie Dykes. Was it possible that marginal bands of flinty crush-rock had been misinterpreted? Fortunately, it is not necessary to revisit the ground to confirm the Survey's findings. For instance, in the collections from Sheet 101 we find (4885), and from Sheet 107 (2757–8, 8600–1, 30672) clearly demonstrating chilled igneous margins. Of these (8600–1) show flinty crush-rock cutting chilled marginal dyke-rock—in (8600) there is unusually obvious incipient crystallization of the crush-rock. Other examples of flinty crush-rock from Sheet 107 are (2320 with incipient crystallization, 2730, 2931, 3046, 3424).

Readers can turn for themselves to Horne's crystal-clear summary of the general story (N.W. Mem., pp. 33, 36–40). He recounts how the intrusion of the Scourie Dykes allows of the recognition of two metamorphisms, widely separated in time—metamorphisms which themselves are composite. The earlier is the pre-Scourie-Dyke metamorphism of the "Fundamental Complex",[1] particularly well displayed in the Assynt district or, as Horne says, from near Scourie to Loch Broom. This is what Sutton and Watson call Scourian, but since it does not affect the Scourie Dykes I prefer to speak of it as the Assynt, or Assyntian, metamorphism. The subsequent metamorphism is intimately connected with post-Scourie-dyke earth-movements. It is widely recognizable in the Assynt district but becomes much more strongly marked northwards from Laxford to Cape Wrath and southwards from Loch Broom and Gruinard Bay to Loch Torridon and Raasay. This is what Sutton and Watson, I think very happily, call Laxfordian.

Horne, speaking for himself, Peach, Clough, and Hinxman, describes how the division into Fundamental Complex and Later Intrusions proves unserviceable northwards from Laxford to Cape Wrath and

[1] In the present paper I follow Clough (N.W. Mem., p. 214) in excluding the Loch Maree sediments from the Fundamental Complex, because of their doubtful age relations. Horne (N.W. Mem., p. 33) groups them as a special part of this complex—but this need lead to no confusion.

Eribol, where Laxfordian movement, coupled with intrusion and recrystallization, is predominant (N.W. Mem., p. 105). The Scourie Dykes have become more or less hypothetical, but seem to " appear in the form of bands of hornblende-gneiss, which can be followed only for short distances " (N.W. Mem., p. 37) ; but the granites and pegmatites of the Laxford district, " injected mainly along the early foliation planes of the gneisses—so minute and at the same time so extensive " (giving rise to what Sutton and Watson very properly call migmatite)—continue as a plexus " north to Cape Wrath " (N.W. Mem., pp. 37–8).

Sutton and Watson think it convenient to give a special name, Laxfordian, to the Lewisian Complex as exposed north of Laxford. It may well be. The Laxfordian Complex is in this locality composed of the Fundamental Complex (which they call Scourian, I prefer Assynt), plus Scourie Dykes, plus Laxford intrusions—the whole, except many of the pegmatites, profoundly affected by Laxfordian metamorphism.

A striking feature is the comparative rapidity of the transition northwards from the Assynt to the Laxford conditions of affairs. Doubters should consult Clough's non-dogmatic, but convincing, statement of the case (N.W. Mem., pp. 126–8). The outcrop of what may be called the transition belt is only some 3 miles wide.

Here let me note a field character of the grey pyroxene-gneisses that furnish the main constituent of the Fundamental Complex in the Assynt district. I refer to a bluish opalescence of the quartz, which Teall connects with hairlike inclusions (N.W. Mem., p. 54—I do not know whether it belongs to Assyntian metamorphism or to initial stages of Laxfordian). Clough has traced the gradual north-eastward disappearance of this feature, coupled with intensification of Laxfordian metamorphism. He found that in the south-western part of the transition belt " quartz streaks with distinct opalescence are rare, and in the north-eastern, perhaps, they never occur " (N.W. Mem., p. 127). In keeping with this, Horne tells us that between Laxford and Cape Wrath " pyroxene-gneiss with blue quartz is absent " (N.W. Mem., p. 37).

Here one may, perhaps, stray a moment into the subject of Caledonian displacement. On the north coast, in the Durness–Eribol district (Sheet 114), a well-known layer of Lewisian lies within the Moine Nappe, a little above the base (*Slices* 1328, 2345–2350, 2355, 2402, 2414–2423, 3645, 4350, 15047–8). Teall, together with Peach and Horne, has pointed to the prevalence of zoisite and epidote in this position, often forming part of saussuritic aggregates (N.W. Mem., pp. 58, 116, pl. xliii). I have little doubt that this character is a product of Caledonian metamorphism ; but my particular point is that some

of the saussuritized specimens seem to have started their long Moine journey from a region of Assynt, rather than of Cape Wrath (Laxfordian) character. This view is supported by the finding of examples of hairy quartz (2416, 2419, 4350). Moreover, associated specimens suggest the presence of one or more partially undeformed, though much altered, Scourie Dykes at Sangomore Bay, Durness (1328, 2346, 15048). These observations are, so far as I know, new ; and I hope they may prove of use to other workers. At the same time, Caledonian thrusting of one style of Lewisian over another has long been recognized elsewhere on the Moine tectonic front. The main observer is Clough, and I have already furnished references (1935, pp. 157–9).

The southward transition from Assynt style to a reconstruction that completely camouflages the distinction between Fundamental Complex and Scourie Dykes is spread over a much larger territory than its northward counterpart near Laxford. Horne places the southern limit of the comparatively simple Assynt region at Loch Broom and Gruinard Bay (N.W. Mem., p. 37). Here, Gunn found all Scourie Dykes metamorphosed to massive epidiorite, except for a few locally converted to hornblende-schist (N.W. Mem., p. 185). The common dolerite type of Assynt is apparently wanting ; but there is still no difficulty in separating dyke from complex.

With varying degrees of difficulty, the possibility of such separation persists southwards past Loch Maree to Loch Torridon, a distance of 30 miles. Here, Laxfordian metamorphism is so far advanced that Hinxman makes the following statement : " Towards the shore of Loch Torridon the older banding [of the Fundamental Complex] becomes almost entirely replaced by the secondary [Laxfordian] foliation " (N.W. Mem., p. 255). Even so, in Rona and Raasay, to the west and south, Teall found suggestions of an order of succession from Fundamental Complex through hornblende-schist Scourie Dykes to certain pink gneisses which he thought corresponded with the Laxford granites (N.W. Mem., pp. 259–261).

Within the extensive transition belt just outlined, the most amazing structural complications have been deciphered, mainly by Clough (N.W. Mem., pp. 39, 192, pl. xxx). In a war-delayed obituary I once wrote (1923, p. 237) : " He mapped in minute detail ' folded dykes ' in the Lewisian Gneiss (Sheet 91 of the 1 in. map of Scotland), thus advancing a tectonic claim which is probably without parallel in the literature of the subject. (For my own part I feel very doubtful whether the igneous rocks, which have been traced through the folds, started their career as vertical dykes ; but those who know the district seem convinced that such is the case.)."

Further consideration of the published evidence has removed most of my hesitation. In fact, I accept, almost unreservedly, Clough's

view that, in the Loch Maree district, Fundamental Complex and originally vertical Scourie Dykes have been folded into pronounced and extensive " anticlines " and " synclines " of Laxfordian date, and that in one of these " synclines ", north-east of Loch Maree, the structural succession is :—

Fundamental Complex with deformed Scourie Dykes
Loch Maree Sedimentary Schists with immense sheets of Loch Maree Hornblende-Schists (N.W. Mem., pp. 97, 238–244), but without Scourie Dykes
Fundamental Complex with deformed Scourie Dykes

Clough admits that the Loch Maree hornblende-schists do " in portions " " resemble the sheared basic [Scourie] dykes ", but he points out that they often individually form vastly bigger masses, are not noticeably transgressive, and tend to be " more finely foliated " with minute needle crystallization of their hornblende. He remarks confidently that " they are never intersected by [Scourie Dykes], even in places where the adjoining gneiss is repeatedly traversed by " these latter (N.W. Mem., p. 240). He goes on to suggest, rather lamely I think, that the Loch Maree hornblende-schists may represent sills intruded into the sediments fed by Scourie Dykes. There is here no explanation of the common petrographical dissimilarity of the two suites—though I admit this dissimilarity may have resulted from differences in metamorphism connected with differences of environment. Apart from this we learn, incidentally it is true, that Clough with his intimate knowledge of field appearances, was ready to believe that *all* the metamorphism of the Loch Maree hornblende-schists, like that of the Scourie Dykes, is of Laxfordian date—an extremely important fact.

Slices of Loch Maree hornblende-schists are : Sheet 91 (1848, 3746–7, 4439, 4995–6) ; Sheet 92 (4323, 4423–4, 4773, 4786, 5119, 5120, 5491, 6339–6341).

Slices of Scourie Dykes of the same general neighbourhood are : Sheet 91 (3744–5, 4192 A, B, 4193–4, 4345, 4434) ; Sheet 92 (4662–3, 4665–6, 4785, 5118).

Clough's views regarding the probable relation of Hicks' Loch Maree sediments to the igneous part of the Fundamental Complex are most clearly stated in relation to the Glenelg association above the Moine Thrust, which he regarded as a tectonic repetition of the Loch Maree association of the foreland : " There is no evidence," he says, " that the altered sediments, or paragneisses, are unconformable to and younger than the rocks of igneous origin, nor are the former ever distinctly transgressed by the latter. The working hypothesis which commends itself to the writer is that the series represents a complex in which the oldest rocks are of sedimentary origin and have been injected and greatly altered by a variety of igneous rocks, intruded under peculiar conditions and considerable pressure " (1910, p. 19).

On the other hand, I agree with Gunn and Peach that the apparent absence of Scourie Dykes from the Loch Maree sediments does strongly suggest that the latter are of post-Scourie-Dyke age (Peach and Horne, 1930, p. 40). The occurrence of these sediments and accompanying hornblende-schists, sandwiched in, north-east of the Loch, as a mighty slice between ortho-gneisses of the Fundamental Complex, above and below, I ascribe to earth-movement (I think everyone does). The approximate parallelism of Scourie Dykes in the orthogneisses to boundaries between these latter and the sediments I take as evidence of extensive decollement. I imagine (with some originality) that the sediments travelled for a time over the ortho-gneisses, and in the more superficial part of these latter dragged Scourie Dykes, along with other structures, into something approaching horizontality. Subsequent folding and thrusting did the rest. The deformation was conducted at a high temperature, and accompanied by a limited amount of intrusion. Clough has pointed out that " pegmatites of later age than the basic dykes are abundant in two [' anticlinal '] areas in the Loch Maree district " (N.W. Mem., p. 212).

In passing I may point out that the Loch Maree sediments (I do not here include the geographically isolated kyanite gneisses of the district) seem to be less highly metamorphosed than their counterparts in Glenelg, Coll, Tiree, and Harris. For instance, in their metamorphic dolomites, diopside is almost wanting and forsterite has not been observed.

Slices of Loch Maree sedimentary schists (N.W. Mem., pp. 75–84, 214–238) :—

Loch Maree outcrop : Sheet 91 (5475–6, 5482) ; Sheet 92 (842–4, 1326, 1842–3, 4320–2, 4324, 4326–8, 4408–4422, 4664, 4758–9, 4768–9, 4784, 4787–8, 4790–3, 4795, 5109, 5475–5482, 5494).

Gairloch outcrop : Sheet 91 (1852–3, 1858, 3751–4, 3836, 4189, 4190, 4196, 4340, 4348, 5123, 5125–6).

Loch Kerry outcrop : Sheet 91 (3749, 3755, 4186, 4188, 5122, 5124, 5127, 5130).

Slices of kyanite gneiss, 4 m. N.N.E. of Letterewe (N.W. Mem., pp. 83, 237) :—

Sheet 92 (5115–5117) with (5114 actinolite rock).

Returning to what all agree is Fundamental Complex, we find that its nature must have differed materially north and south of Gruinard Bay, even in pre-Scourie-dyke days. Northwards, in the Assynt district, the characteristic country rock into which the Scourie Dykes were intruded, was quartzose pyroxene-gneiss (N.W. Mem., pp. 53–6, 156, etc.), with basic (N.W. Mem., pp. 50–3, etc.) and ultrabasic (N.W. Mem., pp. 44–7, etc.) forerunners ; while southwards it seems to have been in large measure mica- or hornblende-gneiss.

The pyroxenic assemblage of Assynt is spoken of by Sutton and Watson, in their papers read in 1950, as a charnockitic suite ; and this led to valuable contributions in the discussion from three charnockite

experts, Groves, Davidson (who had already made the comparison), and Fermor. Teall, in citing foreign analogues, had mainly drawn upon Williams' account of " The Baltimore Gabbros " (1886). He did not mention Holland's 1900 memoir on the charnockites, because, as stated in an apologetic footnote, his manuscript for the 1907 memoir was completed in 1895. The experts of the 1950 discussion seem to have more or less agreed that it is useful to call the Assynt suite charnockitic, although there is nothing in it closely comparable with type charnockite—a microcline-rich-hypersthene-granitoid-rock.

Holland regarded his charnockite series as plutonic igneous rocks, unmetamorphosed. Teall could not make up his mind whether the Assynt ultrabasics and basics were metamorphosed or no. Sutton and Watson regard them as metamorphosed, and the discussion which followed their 1950 papers appears to favour this interpretation. The rocks are certainly not what we generally call normal igneous rocks. This is shown among other things by four circumstances :—

(1) The widespread intermediate and acid pyroxene-gneiss, which seems to belong naturally to the same suite as the ultrabasics and basics, is of a type that almost everyone calls metamorphic.

(2) Olivine is characteristic of the felspar-free ultrabasics, but has not been detected in basic representatives where, Clough says, " almost every good exposure shows garnets in some part or other " (N.W. Mem., p. 131).

(3) The felspars of the basic, intermediate, and acid types scarcely exhibit a trace of the zoning one expects in the plagioclase of normal igneous rocks. Grubenman and Niggli have pointed out that " in most metamorphic rocks zoning of individual minerals is exceptional, and where it does occur is less pronounced than in igneous rocks " (1924, p. 424).

(4) The felspars also show almost complete immunity from Laxfordian clouding (see below) that affects similar felspars in associated Scourie Dykes (cf. N.W. Mem., pl. xlvii, 2) ; this suggests inoculation during previous (Assyntian) metamorphism. (There appears to be one marked exception—4187 from Sheet 91, an altered rock collected by Clough as Fundamental Complex and accepted by Teall as such, N.W. Mem., p. 63. Its microscopic characters, apart from the clouding of felspars, make Clough's determination almost certain.)

Slices of the pyroxenic suite of the Assynt Fundamental Complex, showing comparatively little Laxfordian metamorphism :—

Ultrabasic, mostly called by Teall olivine-hornblende-pyroxenite : Sheet 101 (4459, 4460) ; Sheet 107 (1824–5, 2327, 2724, 2934, 3380, 3384, 3386, 3390, 3393, 3396, 3403, 3411, 3415, 3946, 4893, to which we may add 2326 hornblendite, 3419 anthophyllite-hypersthene-hornblendite, 4648 dunite).

Basic, mostly called by Teall pyroxene-granulite, with garnet, or Baltimore gabbro, without : Sheet 107 (1848, 1820, 2002, 2063–4, 2314, 2321, 2323, 2990, 2994, 3046, 3306, 3381–2, 3389, 3392, 3397, 3404, 3406, 3408, 3414, 3940, 3962, 4470, 4888, 30652, 30655).

Intermediate, called by Teall pyroxene-gneiss : Sheet 107 (2989, 2996, 3416, 4890, 15012).

Acid, called by Teall pyroxene-gneiss : Sheet 107 (2995, 3385, 8722).

Slices of above suite considerably altered, in many cases by Laxfordian metamorphism :—

Ultrabasic, non-schistose : Sheet 101(861) ; Sheet 107 (1832–3, 2065, 2723,* 3398, 3400, 3402, 3942, 3955, 4467, 4647,* 4651,* 35690–2).

Ultrabasic, schistose : Sheet 107 (2325,* 2763, 2764,* 2953, 2955,* 3944, 3958, 4894).

Basic, non-schistose, non-saussuritic : Sheet 107 (853, 855, 3399, 4448, 4461, 4464–5, 4468, 7842, 15013, 30677).

Basic, non-schistose, saussuritic : Sheet 107 (3391, 3409, 3413, 30653–4).

Basic, schistose : Sheet 107 (3237, 3239, 3240, 4443).

Intermediate, non-schistose, non-saussuritic : Sheet 101 (3033, 30645) ; Sheet 107 (847, 1826, 2316, 2984, 2986, 2988, 2991, 3383, 3387, 4447, 4469, 4891–2, 7841, 30676).

Intermediate, non-schistose, saussuritic : Sheet 107 (2312, 3479, 4463).

Acid, non-schistose, non-saussuritic : Sheet 107 (849, 2066, 2315, 2997, 3234, 3395, 3405, 3407, 4445, 4889, 30656, 30674–5).

Acid, non-schistose, saussuritic : Sheet 107 (1324).

Intermediate and Acid, schistose : Sheet 107 (3739, 3740, 3941, 3953, 4442, 4446, 4449–4454).

* With anthophyllite.

Here, for comparative purposes, we may note certain features, additional to clouded felspars, which are found among the least altered Scourie Dykes. It is a lucky accident that these rocks, in their mineralogy, closely approach the least altered members of the Assynt suite.

(1) Some Scourie Dykes carry both olivine and felspar (2319, 3307, 8123, 30650–1, 30673).

(2) The felspars of little-altered Scourie Dykes show more zoning than do those of the Assynt Complex, though never with the sharpness that one expects in unaltered igneous rocks.

(3) Even away from chilled margins, the little-altered dykes exhibit a marked tendency to idiomorphism of their felspars or pyroxenes, or both. The usual thing is to find felspars projecting into subophitic augite ; while, occasionally, well-formed pyroxenes, especially enstatite, lie embedded in big felspars. By contrast, the felspars and pyroxenes of the Assynt suite show no trace of idiomorphism.

Slices of Scourie Dykes little affected by Laxfordian metamorphism, except as regards clouding of felspars :—

Ultrabasic, called by Teall picrites : Sheet 107 (3048, 3307–3310, 3960, 4466, 6281, 7957, 8123).

Basic, mostly called by Teall dolerite : Sheet 101 (2742, 2745, 3908) ; Sheet 107 (2318–9, 2728, 2931, 2944, 3042–4, 3097, 3103, 8602–3, 8627, 30650–1, 30673).

Slices of Scourie Dykes much affected by Laxfordian metamorphism :—

Ultrabasic, non-schistose : Sheet 101 (3947) ; Sheet 107 (2937–8, 30662).

Ultrabasic, schistose : Sheet 107 (2939–2943). An anthophyllite-schist Sheet 92 (5118) from south of the Assynt district also deserves notice (N.W. Mem., p. 49).

Basic, not schistose, usually retaining clouded felspar, mostly called by Teall epidiorite (*a*), retaining original igneous texture : Sheet 101 (3068,

3907, 4693) ; Sheet 107 (2317, 2371, 2759, 2760, 2935, 2944, 3045, 3959, 6279, 8606, 30649, 30670–1).

Basic, non-schistose, almost completely reconstructed, with saussurite, mostly called by Teall epidiorite (*b*), devoid of igneous texture : Sheet 101 (2089, 2741, 2743–4, 2746, 2753, 3067) ; Sheet 107 (3948–9).

Basic, schistose, often with epidote, called by Teall hornblende-schist, including links with non-schistose epidiorite. Sheet 101 (2747–2752, 2754–6, 3050, of which 2747 is illustrated by Teall as epidote-amphibolite (N.W. Mem., pl. xlviii, 2) ; Sheet 107 (2726–7).

In interpreting the Laxfordian metamorphism of the Scourie Dykes, Teall at first made the serious mistake of thinking that it was dynamic metamorphism at " ordinary temperatures " (1855, p. 141). Subsequent personal experience in Devon and Cornwall, combined with reading, led him to abandon this opinion. He now claimed that the Laxfordian metamorphism was dynamic metamorphism conducted at temperatures such as prevail in granite aureoles (1918, pp. 5, 9). In so far as this conclusion concerned the production of hornblende-schist from dolerite, Teall was probably voicing what had become by 1918 a widely accepted proposition.

On the other hand, Teall had always pointed out that the Laxfordian metamorphism of Scourie Dykes had resulted in two contrasted end products. One of these is massive non-schistose epidiorite ; the other hornblende-schist. The production of the massive epidiorite seems unrelated to deformation (other than hypothetical compression or vibration), and so it seems to me had better not be called dynamic at all, but rather thermal.

In 1931 MacGregor, in a paper that deserves very close attention, interpreted the clouding of felspars in Scourie Dykes as indicating " a preliminary phase of thermal metamorphism unaccompanied by appreciable shearing stress " (1931, p. 530). In the discussion of Sutton and Watson's papers (read 1950) I supplemented MacGregor's statement by dwelling on the regional distribution of the phenomenon, remarking that in the Assynt district all Scourie Dykes " which have not suffered more obvious reconstruction have clouded felspars ". In their 1951 *Geological Magazine* paper Sutton and Watson seem to misunderstand MacGregor's position. They say " MacGregor (1931) ascribed the clouding of felspars in a dyke at Scourie to thermal metamorphism. The phenomenon is, however, widespread throughout the least-altered dykes, and appears to be a normal part of regional Laxfordian metamorphism " (1951, p. 28). MacGregor had, as a matter of fact, explicitly described the phenomenon as affecting " Scourie Dykes ", not merely " a dyke at Scourie ". Also he obviously had meant his " preliminary phase of thermal metamorphism " to be understood as a phase of the familiar post-Scourie Dyke, or Laxfordian, metamorphism of the district.

Apart from this confusion, I agree in large measure with the conclusions reached by Sutton and Watson in their 1951 *Geological Magazine* paper. They seem, however, to underrate the extent to which epidote and albitic felspar have been produced by Laxfordian metamorphism in the Assynt district. They note rare epidote in Teall's type Scourie Dyke, but as a generalization they say that " albite and epidote do not appear " in the Scourie Dykes (1951, p. 31). This does not agree with the Survey slices. Those listed on page 163 as " non-schistose, almost completely reconstructed ", all contain significant, sometimes abundant, epidote. Teall has said of them : " The typical rocks of the second group (*b*) of epidiorites are devoid of igneous structure. They are essentially composed of plagioclase and hornblende, with which some quartz and a mineral of the epidote group are often associated. . . . Epidiorites of this type are extremely common in the central [Assynt] area, and may be obtained from almost any of the basic dykes " (N.W. Mem., pp. 92, 93). The slices listed on page 162 as " basic, schistose " from Sheet 101 have a rich development of epidote, while those from Sheet 107 (2726–7) are essentially epidote-free. I think that this last represents the common condition in the more thoroughgoing hornblende-schists (N.W. Mem., pl. xlix). Otherwise, Teall's remark that in the hornblende-schists " epidote and quartz are occasionally found " might seem an understatement. He adds : " In those rocks which contain epidote the felspar is albite or some closely allied variety " (N.W. Mem., p. 93)—an observation borne out by the Survey collections.

Let us now, while still remaining in the Assynt district, turn to consider the condition of the basic, intermediate, and acid members of the pyroxenic suite cut by the Scourie Dykes. In the 1950 discussion, after referring to the local reconstruction of Scourie Dykes, I continued : " Marked reconstruction of the host-rocks of the Scourie dykes is similarly local in the Scourie–Assynt region, and may be of either non-schistose or schistose character. The non-schistose developments have been specially well described by Teall." Slices are quoted on page 163. Useful references are (N.W. Mem., pp. 50, 55–6, 61–3, 113, pl. xliv). I mentioned at the time that Harker had figured an example of this non-schistose type from near Scourie, and had remarked that it " reproduces many of the features of simple thermal metamorphism " (1939, fig. 148A). I might have added that Teall long previously had pointed out that the biotite, frequently found in these rocks, " both in its character and mode of occurrence, more closely resembles that of contact rocks than that of normal igneous products " (N.W. Mem., p. 62).

One might naturally expect to find in the North-West Highland Memoir some claim that a considerable part of the above non-schistose

type of alteration in the Fundamental Complex is of the same date, Laxfordian, as the distinctly similar type affecting Scourie Dykes; but no such suggestion seems to have been advanced until a later date. It will be realized that, though its probability may strike anyone looking through a sliced collection, its certainty may be difficult to demonstrate in the field. However, the related claim that the much more field-apparent schistose type of alteration is contemporaneous in country rock and dykes was early established (N.W. Mem., pp. 63–5, etc.); and eventually we do find Teall boldly affirming: "Just as the granitoid pyroxene-gneisses pass into granulitic hornblende-gneisses, comparable to the hornblende-schist of the dykes, *in* the zones [of shearing], so, *outside* them, the same gneisses frequently become hornblende-gneisses of a peculiar type, comparable to the epidiorites, in which the hornblende occurs in aggregates without the development of secondary foliation" (1918, p. 7).

I may add that the intermediate and acid members of the Assynt pyroxenic suite, where they have recrystallized without deformation, present some of the most beautiful microscopic objects afforded by Scotland.

REFERENCES

BAILEY, E. B., 1923. C. T. Clough, M.A., LL.D., F.G.S., *Trans. Edin. Geol. Soc.*, xi, 236.

—— 1935. The Glencoul Nappe and the Assynt Culmination. *Geol. Mag.*, lxxii, 151.

CLOUGH, C. T., 1910. *in* The Geology of Glenelg, Lochalsh, and South-East part of Skye. *Mem. Geol. Surv.*

GRUBENMAN, U., and NIGGLI, P., 1924. *Die Gesteinsmetamorphose*, vol. 1. Berlin.

HARKER, A., 1939. *Metamorphism.* 2nd Ed. London.

HOLLAND, T., 1900. The Charnockite Series. *Mem. Geol. Surv. India*, xxviii, 119.

MACGREGOR, A. G., 1931. Clouded felspars and thermal metamorphism. *Min. Mag.*, xxii, 524.

N.W. Mem., *see* Peach and Others, 1907.

PEACH, B. N., HORNE, J., CLOUGH, C. T., TEALL, J. J. H., and Others, 1907. The Geological Structure of the North-West Highlands of Scotland. *Mem. Geol. Surv.*

PEACH, B. N., and HORNE, J., 1930. *Chapters on the Geology of Scotland.* Oxford.

SUTTON, J., and WATSON, J., 1950. *Proceedings Geol. Soc.*, pp. 51–3, with Discussion, pp. 53–64.

(1) The metamorphic history of the Archaean rocks of Loch Torridon, Ross-shire, by J. Sutton.

(2) The metamorphic history of the Archaean rocks of Scourie, Sutherland, by J. Watson.

(3) A chronological classification of the Archaean rocks of the mainland of North-West Scotland, by J. Sutton and J. Watson.

—— —— 1951. Varying Trends in the Metamorphism of Dolerites. *Geol. Mag.*, lxxxviii, 25.

TEALL, J. J. H., 1885. The Metamorphosis of Dolerite into Hornblende-schist. *Quart. Journ. Geol. Soc.*, xli, 133.

—— 1918. Dynamic Metamorphism. *Proc. Geol. Assn.*, xxix, 1.

WILLIAMS, G. H., 1886. The Baltimore Gabbros. *Bull. U.S. Geol. Surv.*, No. 28.

A Note on Rhythmic Layering in the Ultrabasic Rocks of Rhum

By L. R. Wager and G. M. Brown
Department of Geology and Mineralogy, Oxford

(PLATE VII)

Abstract

Preliminary observations indicate that the rhythmically varied layers of ultrabasic rock in Rhum form part of a layered intrusion built up from below rather than a series of separate injections.

THE remarkable sheet structure of the ultrabasic rocks of Allival, Askival and other mountains in Rhum which has been described by Harker (1908) as a succession of peridotites and allivalites of various kinds, shows a clear rhythm in the conditions of formation. This rhythm has escaped earlier observers, probably because they conceived the layering as due to successive injection. During a recent visit we found that the more olivine-rich part of the rhythmic unit, usually to be broadly described as peridotite, shows little or no banding and apparently formed under tranquil conditions. Upwards the peridotite becomes more feldspathic and passes into allivalite or even into a plagioclase rock; simultaneously the effects of flow become more evident giving banded and, in some cases, well laminated rocks. The major rhythmic units attain a thickness of 100 or so feet but minor or partial rhythms also occur suggesting small changes in the intensity of the flow movement. In the more feldspathic rocks, accumulated under conditions of vigorous flow, xenoliths of peridotite and allivalite often occur. These are not considered as fragments from the immediately overlying or surrounding rocks incorporated during sill-like injection but the result rather of the disruption elsewhere of earlier formed layers which were transported to their present position by flow movements of the magma. A tendency to develop gravity stratification in narrow bands as in the Skaergaard intrusion (see Wager and Deer, 1939) was found occasionally and then only poorly developed in the leucocratic part of the major rhythmic unit. However, such gravity stratification helps to indicate that the pile of ultrabasic rocks has been built from below upwards.

The truly remarkable rock called harrisite by Harker (1908, p. 88 and Fig. 26) shows a new and unexpected type of structure also indicating bottom accumulation. An equigranular peridotite, often with slight indications of banding, alternates with layers of olivine and feldspar rock, the structure of which indicates upward growth of long branching olivine crystals (Plate VII). After a band a few inches or a few feet thick of this upward growing olivine, with plagioclase as interstitial poikilitic masses, there is renewed formation of the

equigranular peridotite, which is interpreted as a precipitate of discrete crystals submerging the layer of coral-like, upward-growing olivines. This structure when well developed provides further evidence of the upward building of the pile of ultrabasic material. A layer with harrisite structure occurs in one at least of the major rhythmic units on Askival, Allival and Barkeval. On Askival another layer showed upward growth of pyroxenes enclosing olivine crystals poikilitically and overlain by a somewhat laminated allivalite interpreted again as a precipitate of discrete crystals.

The sheet structures shown by the ultrabasic rocks of Rhum are developed with even greater perfection than Harker's maps suggest. Thinking of the allivalites and peridotites as successive sheet injections, he would hardly have expected widespread uniformity giving the same vertical sequence at different places, but this is the case and is reasonable on the alternative view of the sheets being the result of bottom accumulation. During our preliminary visit we saw sufficient to make it clear that it will be possible to map individual sheets over wide areas much as a normal series of sedimentary rocks may be mapped. It will be possible to identify many of the individual sheets by special characteristics, as, for instance, the development of harrisite structures in the sheet already mentioned. It will be of great interest to investigate in detail the structures of these rocks and also their mineralogy; there is some evidence from the data given by Harker that between the lower and the higher units of the layered series there are differences in composition of the minerals which belong to solid solution series.

After a visit to Rhum in 1943 Sir Edward Bailey (1945, p. 182) gave it as his opinion that the ideas developed in the study of the Skaergaard intrusion probably could not be transplanted to Rhum. There are many new features shown by the Rhum rocks, and this is perhaps to be expected as they are very different in composition from the Skaergaard rocks, but we are satisfied that the fundamental characteristic of the Skaergaard intrusion, namely accumulation of material from the bottom upwards, is responsible also for the sheet structure of the Rhum rocks. During rapid traverses over the rocks surrounding the ultrabasics we found that the few observations we were able to make were in general agreement with Bailey's reinterpretation of the Tertiary tectonics. We did not find evidence, however, for a eucrite intrusion of ring dyke form round the foot of Allival and Askival and later than the ultrabasics. It seemed to us more likely that there is a narrow marginal eucrite facies without directional structures which passes inwards, first into obscurely layered rocks and then, after several hundred yards, into the well layered series.

We are grateful to Lady Bullough for permission to visit the island of Rhum and to Professor W. Fisher Cassie, of King's College,

Newcastle, who arranged our visit and took the photograph illustrating this note.

REFERENCES

BAILEY, E. B., 1945. Tertiary Igneous Tectonics of Rhum (Inner Hebrides). *Quart. Journ. Geol. Soc.*, c, 165–191.

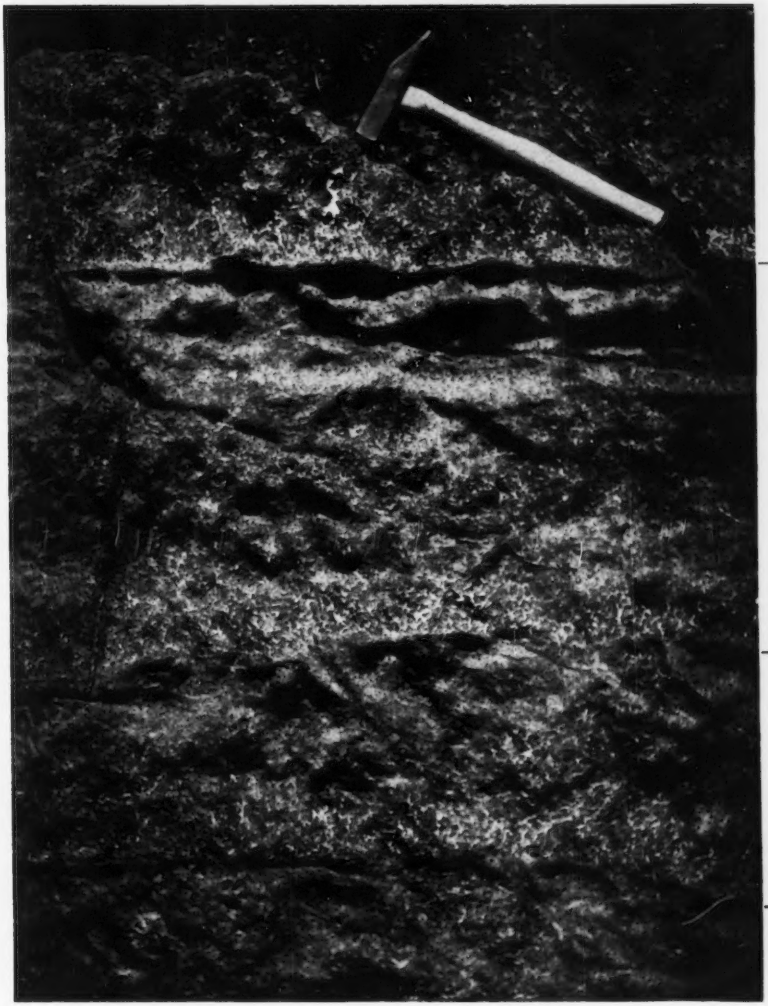
HARKER, A., 1908. The Geology of the Small Isles of Inverness-shire (Sheet 60). *Mem. Geol. Survey.*

WAGER, L. R., and DEER, W. A., 1939. Geological investigations in East Greenland—Part III. The Petrology of the Skaergaard Intrusion. *Medd. om Grønland*, cv, no. 4, 1–352.

EXPLANATION OF PLATE VII

The base of successive layers of harrisite is indicated by a, b, and c. Each layer appears to have been formed by the upward growth of long branching olivines, with development of plagioclase interstitially. This structure is best seen in the c layer. The harrisite layers are each overlain by an equigranular peridotite, best seen beneath the c layer.

Hillside ½ mile W.N.W. of centre of Loch an Dornabac and 1½ miles N.N.E. of Harris Lodge. Photo by W. Fisher Cassie.



VERTICAL ROCK FACE SHOWING DEVELOPMENT OF ZONES WITH HARRISITE STRUCTURE.

A New Structure in the Forest Marble of Oxford

By J. A. Douglas (Dept. of Geology, Oxford University)

(PLATE VIII)

Abstract

An account is given of a new minor structural feature recently found in the Forest Marble of Bladon, Oxfordshire, resembling Pit and Mound structure, and various suggestions as to its mode of origin are discussed.

MINOR structural features, such as current-bedding, ripple-marks, tracks of organisms, and worm casts are so familiar in the limestones of the Forest Marble, all indicative of their formation in a shallow-water, littoral environment, that after demonstrating them to students for many years the discovery of what in the author's experience is an entirely new or undescribed example seems to be worthy of record.

The chief interest in this apparently unique occurrence lies in the remarkable uniformity it displays over a comparatively large area of bedding, the extent so far exposed amounting to about 2,000 square yards, and at the same time in its localization within the limits of a single quarry, for careful search has failed to reveal it in the numerous exposures afforded by other quarries in the immediate neighbourhood, nor have I been able to find any reference to it in the copious literature on the Forest Marble or similar Jurassic rocks.

The structure was first discovered some two years ago in the Wychwood beds of the " Forest Marble " series in a quarry situated at Bladon, near Woodstock, which is being actively worked for stone used chiefly for road-foundations in the district. It lies on the east of the road about 150 yards due south of Blenheim Home Farm at the spot marked Hensington on the 6 in. map, and is referred to by Arkell (1933, p. 181) as Tolley's New Quarry Bladon.

The rock in question occurs in a well-defined band, usually about 2 or 3 inches thick, which can be traced continuously round the entire face of the quarry, some 3 feet below ground level.

It is a sandy limestone, analysis of which gave the approximate average composition—60 per cent calcium carbonate, 23 per cent sand, and 16 per cent clay, the last-named occurring in the form of thin films between the coarser bedding planes.

The structure, which is remarkably regular over the whole extent of its outcrop, consists on the upper surface of very uniform, evenly spaced, shallow, circular depressions about 4 mm. in diameter, and on the counterpart or lower surface of hemispherical projecting papillae about the size of buckshot, averaging about thirty-five in number to the square inch.

Vertical sections, moreover, show that the structure is repeated throughout the entire thickness of the band in a continuous, superimposed series, each projection fitting into a corresponding depression of the bedding plane immediately below it, so as to form vertical rows of cups. The bottom of each cup is slightly flattened and bears at its centre a circular scar suggesting the termination of a small pipe.

Associated with these are the familiar " double-line " ramifying tracks of uncertain origin, but which must clearly have been formed by annelids, small crustacea or other organisms. These, it should be noted, are convex on the upper surface with a concave counterpart on the base of the overlying layer.

That the structure here described is syngenetic with the deposition of the beds and not a subsequent product like the growth of calcareous tufa commonly found on the underside of many bedding-planes in a limestone formation is shown by the obliteration of the depressions where these have been crossed by the " annelid " tracks (Pl. VIII, Fig. 1).

A growth of this nature does, in fact, occur at the base of the limestone band where water has seeped out above an underlying 4 in. bed of clay.

The primary question involved is whether it is due to organic or inorganic agencies, about which many different and conflicting views have been expressed.

The possibility that the surface depressions are imprints caused by rain or hail is at once disproved by their even spacing, uniformity of size, absence of coalescence and vertical continuity through several inches of rock.

A more plausible explanation is that they are examples of " Pit and Mound " structure, due to ascending currents of gas or liquid through soft sediment, described by Kindle (1916), Twenhofel (1932), and others, and recently diagrammatically illustrated by Schrock (1948) who cites it as a reliable criterion for determining top and bottom features.

In the case of gas-bubbles rising vertically through mud, shallow craters or blister-like mounds with a central depression are produced at the points of emergence, and some indication of their upward passage might be expected to be visible in the pipes along which they ascended if these happened to be preserved.

In accounts of experimental work on the origin of Pit and Mound structure reference is invariably made to the flocculation and settling of fine mud, and the peculiar mechanics of formation have been described by Schofield and Keen (1929, p. 492). It would appear to be unlikely, therefore, that such a feature could occur except in a dominantly argillaceous deposit and, if due to escape of gas,

one where organic matter present in the mud was undergoing decomposition.

Here, however, we are dealing with a sandy limestone, of fairly coarse grain, clay being present only in the form of extremely fine interbedded laminae, while the pipes which are well-preserved throughout the rock (Fig. 2) by their inverted V-formation point to a downward as opposed to an upward movement of sediment, and moreover they terminate in mounds on the under and not the upper surface of the bedding planes, for it is hardly necessary to state that in the present occurrence we are concerned with undisturbed strata in their original position of sedimentation. A vertical section clearly shows that the sand, lining or filling the tubes, where it passes through a clay lamina is derived from the overlying and not the underlying layer.

Comparison may also be made with the so-called " Sand-holes " which sometimes are found on a strand line, due to air vents caused by the action of waves passing over the beach.

These have been described by Palmer (1928, p. 176) as being vertical where they perforate the surface, irregularly spaced, with diameters up to 6 mm., and sometimes very numerous on sandy beaches. He states that such holes are frequently found in fossil form labelled as " worm-tubes " under the impression that they had been filled and preserved, but it is probable that they are air chambers formed by wave action.

Twenhofel (1932, p. 684) remarks that sandholes are extremely common on sand beaches, falling water leaving the beach covered with thousands. Occurrences in the geologic column, he states, should be rare, but as they form in the same environment as swash marks, whose preservation is known, it seems probable that some rain prints may be sand holes.

From many considerations, however, but particularly the even distribution of the pits and the undisturbed nature of the " annelid " tracks, it seems quite unlikely that the stucture can in any way be ascribed to wave-action.

Somewhat different features, on the other hand, can, it is true, be produced in the case of ascending currents of water, and Schrock, in the right-hand front corner of his diagram (op. cit., fig. 94, p. 134), shows how a small crater may be formed by a spring-like current excavating the mud at the surface instead of building it up. The counterpart preserved on the underside of the covering layer would then be a mound convex downwards.

Nevertheless, it seems difficult, if not impossible, to explain the remarkably even distribution of an immense number of small springs through what must have been a freely permeable deposit of calcareous sand, disregarding the fine interbedded laminae of clay, unless these

currents were produced by organisms such as mollusca in the underlying bed, for which there is no evidence; nor could a series of downward pointing V's be produced except by subsequent collapse.

A further, though somewhat remote possibility is that the structure might have been in part of chemical origin, akin to cone-in-cone structure, whereby centres of calcite crystallization were distributed throughout a sandy matrix. Even though subsequent leaching may have destroyed all trace of this, the presence of organic tracks shows that the structure was of syngenetic and not epigenetic origin.

If we now turn to previous records of analogous structures the only one that seems at all comparable with our own is that described by Madigan (1928, p. 213) from the Point Marsden series of Kangaroo Island, Australia, which he considers to be Ordovician.

The resemblance is indeed so striking that it may well be repeated here:—

> As sandy and muddy layers alternate, the conditions were ideal for the preservation of any markings on the mud surfaces, some of which were pitted all over with what appeared to be raindrop imprints. These little pits are from one-tenth to one-twentieth of an inch across and almost in contact. They average about 45 to the square inch. They are better seen in most cases as little blobs the size of shot on the underside of the overlying layer. The bands showing this phenomenon are about half an inch thick, and it was noted that there were pits on one side of the slab and projections on the other.
>
> A thin section unexpectedly disclosed that the depressions went right through the half-inch slabs, and that a pit on one side was connected with a projection on the other. It was noted in the field that the pits were on the upper side of the slabs *in situ*. The thin section of the half-inch slab shows it to be composed of very fine material in bands of varying fineness, as many as six bands being definable. The section is marked by vertical lines, the cores of each pit, in the form of conical depressions at each surface between the bands, down which the material of the band above has sunk into that below in a long tapering cone. . . . The upward path of air bubbles in muds is suggested but material has been carried from each layer downwards, and also the pits are so numerous and uniform in size and spacing.
>
> In addition to the sun cracks, ripple marks and so-called rain prints, there are other markings on the slabs suggesting worm casts occurring in little heaps, and tracks of crustaceans.

The above description, which word by word might almost be a repetition of our own, is quoted by Schrock as probable Pit and Mound structure, although Madigan did not apparently favour this view and the evidence is by no means conclusive.

Nevertheless, assuming this to be the correct interpretation, a comparison of his figures (op. cit., pl. xx) with those of the Forest Marble occurrence given here shows certain points of dissimilarity.

The pits appear to be relatively deeper, sharper in outline, and less evenly spaced, while the general impression is one of a concretionary, botryoidal growth with concentric shells, rather than parallel evenly sized and spaced tubes.

It is, then, this very regularity in size and spacing of the tubes in our present example that seems to preclude an inorganic origin, and we are led to believe that the structure is primarily due to the agency of some form of organism. Here, however, we are faced with the difficulty of accounting for the occurrence of any such organism only in this one restricted spot, for if they were vertical worm-tubes it would indeed be remarkable that similar tubes appear to be unknown elsewhere in the Forest Marble, and repeated search has failed to reveal them. Any fanciful resemblance to the growths of calcareous algae, such as *Collenia*, can be ruled out for columnar colonies of this nature invariably have their convexity upwards (Fenton and Fenton, 1937). It thus seems to be clear that we must look for some local and unique set of ecological conditions, and bearing in mind the littoral nature of the whole deposit it is possible that the structure had its origin in a temporary lagoon in which marshy vegetation had gained a foothold, the tubes having been formerly occupied by reed stems around which calcareous sand was drifted. On their decay the hollow cylindrical cavities would soon be filled in by sagging and collapse of their sides.

An occurrence of this type, although admittedly on a larger scale, has been described by H. Woodward from the Fayum (1910, p. 399), and he quotes Moore's discovery of " fossilized reed-stems in a lake deposit of sandy calcareous material on the Tanganyika Expedition.

While no remains of carbonaceous material have yet been observed filling the tubes it is fairly abundant in the form of small scattered fragments in the overlying sandy beds. The 4 in. band of clay immediately beneath the deposit may have been the " seat-earth ", and it is noticeable that unlike many of the other beds of clay in the series it lacks the usual fragmentary shells of small *Ostrea*.

One further point may be mentioned.

Reference to Fig. 1 (Pl. VIII) shows that no circular depression anywhere cuts one of the " annelid " tracks.

But since these must have been formed contemporaneously in the soft unconsolidated sediment, it seems unlikely that continuously ascending currents of water or gas would have failed to penetrate them, whereas any organism crawling through a reed-bed would necessarily part the stems and thus tend to leave an unbroken trail.

If, however, this last explanation is the correct one, it follows that any analogy with the structure described by Madigan from rocks as old as Ordovician can no longer be maintained.

In conclusion, it must be admitted that no satisfactory solution of the problem has yet been established; similar structures, unknown to the author, may have been recorded elsewhere, and other suggestions

will be welcomed. It is, indeed, with this end in view that the present note has been offered for publication.

REFERENCES

ARKELL, W. J., 1933. New evidence on the Great Oolite Succession at Bladon, near Woodstock, Oxfordshire. *Proc. Geol. Assoc.*, xliv, 177–183.

FENTON, C. L., and FENTON, M. A., 1937. Belt Series of the North. Stratigraphy Sedimentation, Palaeontology. *Bull. Geol. Soc. Amer.*, xlviii, 1941–8.

KINDLE, E. M., 1916. Small Pit and Mound Structure developed during sedimentation. *Geol. Mag.*, liii, 542–7.

LYELL, C., 1851. On Fossil Rain-marks of the Recent, Triassic, and Carboniferous Periods. *Quart. Journ. Geol. Soc.*, vii, 238.

MADIGAN, C. T., 1928. Preliminary notes on new evidence as to the age of the formations on the North Coast of Kangaroo Island. *Trans. Roy. Soc. S. Aust.*, lii, 210–216.

PALMER, R. H., 1928. Sand Holes of the Strand. *Journ. Geol.*, xxxvi, 176–180.

SCHOFIELD, R. K., and KEEN, B. A., 1929. Rigidity in weak clay suspensions. *Nature*, cxxiii, 492–3.

SHROCK, R. R., 1948. *Sequence in Layered Rocks.* 1st ed., pp. 132 *seq.*

TWENHOFEL, W. H., 1932. *Treatise on Sedimentation.* 2nd ed., pp. 677–685.

WOODWARD, H., 1910. On some supposed Pholas-borings from the shores of Birket el Qurûn, the Ancient Lake Moeris, of the Fayûm, Egypt. *Geol. Mag.*, xlvii, 398–402.

EXPLANATION OF PLATE VIII

FIG. 1.—Typical upper surface of slab, showing concave depressions and convex " annelid " trails.

FIG. 2.—Cross section of slab showing vertical tubes and nests of cups.

FIG. 3.—Typical undersurface of slab with projecting papillae.

All figures natural size.

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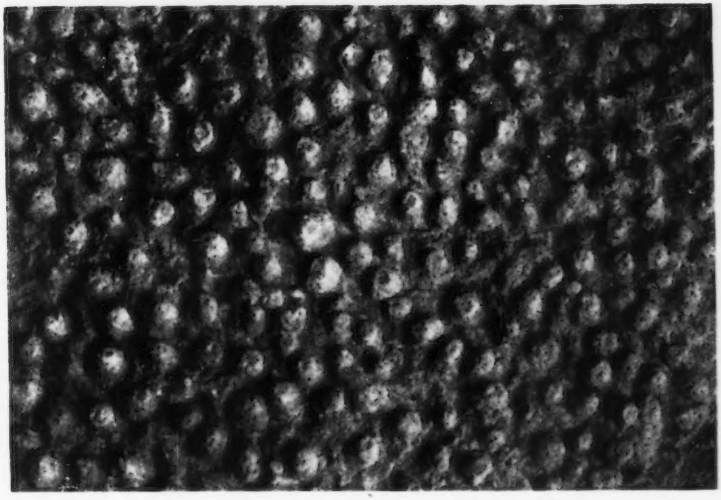

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NEW STRUCTURE IN THE FOREST MARBLE.

A Note on the Progressive Metamorphism of Siliceous Limestones and Dolomites

By C. E. TILLEY

THE stages of progressive thermal metamorphism of siliceous carbonate sediments covering mineral assemblages revealed in the highest grades of alteration were first delineated by Bowen (1940) in a paper which presented an illuminating systematic treatment of the whole subject. In his account the successive stages in the metamorphism of siliceous limestones and dolomites were, in general, linked with a series of reactions of increasing decarbonation in which thirteen steps were traced, involving the appearance of ten distinct mineral phases. With certain reservations these phases could be accepted as indicators of a temperature grade of metamorphism. Investigations carried out since that time have served to confirm the general validity of the scheme set out which thus brings law and order into a field of metamorphism characterized by considerable mineralogical and petrographical complexity.

Later research has at the same time led to some revision incorporating new steps which are, however, essentially in conformity with the principles derived in the original systematic analysis. A note of such revisions consequent on this further study may at this time not be out of place as they serve to fill in the picture of the changing mineral association in response to increasing metamorphism.

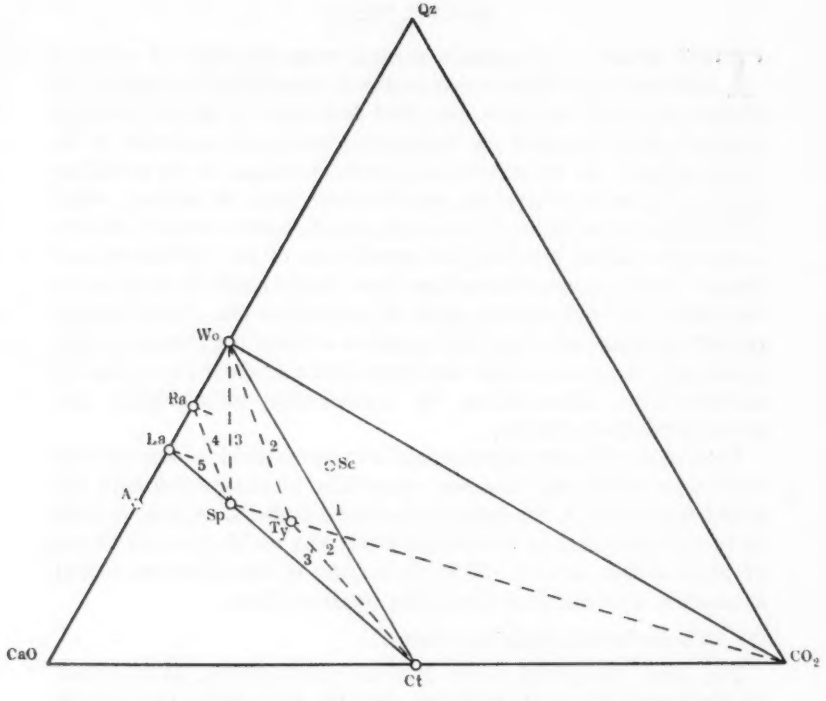
(1) *Siliceous (or Silicated) Limestones.*

The three recognized stages in these compositions, distinguished by the appearance of wollastonite, spurrite, and larnite, can now be extended to include the later known mineral rankinite (Tilley, 1948), and tilleyite, a phase which takes its place in the decarbonation series as a result of Nockolds' study (1947) of its paragenesis and the revision of its earlier-reported chemical composition.

Five stages are thus to be recognized. Rankinite, since its record at Scawt Hill in 1942, has been found in the island of Muck (Tilley, 1947) and still more recently recorded by Agrell (1950) in Ardnamurchan.

A paragenesis which throws further light on the stage of its development is the previously unrecorded occurrence in a Jurassic limestone assemblage, north-west of Camasunary, Skye, in the contact zone of the Cuillin gabbro, where its mineral associates are wollastonite, spurrite, and a gehlenitic melilite. In this environment it forms large amoeboid crystals enclosing both melilite and wollastonite, or is in association with spurrite. The Camasunary paragenesis points directly to a stage of development for the mineral preceding that of larnite. The same inference may be drawn if we derive its position in a decarbonation

series purely from geometrical relations in the triangle representing the phases in the system CaO-SiO_2-CO_2 (Text-fig. 1).



TEXT-FIG. 1.—A condensed diagram showing the progressive decarbonation series in the system CaO-SiO_2-CO_2 in thermal metamorphism. Qz = quartz, Ct = calcite, Wo = wollastonite, Ty = tilleyite, Sp = spurrite, Ra = rankinite, La = larnite [Sc = scawtite, A = Ca_3SiO_5]. The steps 1–5 are indicated.

The position of the tilleyite phase can be similarly deduced and the stage so accorded it is in conformity with its paragenesis in the Carlingford occurrence described by Nockolds (1947).

The successive steps of increasing decarbonation represented by the incoming of the five phases may be summarily indicated graphically in the condensed diagram of Text-fig. 1. With movement away from the CO_2 corner the indicating lines encounter successively the joins wollastonite-calcite (1), wollastonite-tilleyite-calcite (2), wollastonite-spurrite-calcite (3), spurrite-rankinite (4), and spurrite-larnite (5). Further steps, as seen from the relations in the diagram, are possible, e.g. the production of tricalcium silicate (A) and lime itself.

The first of these has not been recorded as a mineral, and though the spurrite-calcite join has a crossed relation to the join tricalcium silicate—CO_2, it does not appear likely that the trisilicate would be stable in the presence of calcite under the physical conditions obtaining in metamorphism. The compound is, however, an important constituent with larnite in completely decarbonated assemblages such as those of Portland cement clinker. In the binary system CaO-SiO_2 it holds a unique position. Absent as a primary phase in the melt, it enters as a constituent phase in the *subsolidus* region, having a temperature-range of existence with both an upper and a lower limit, yielding then, in each case, calcium orthosilicate and lime.

The direct decarbonation of calcite has been reported by Zambonini (1935) in the occurrence of lime in blocks of limestone enclosed in Vesuvian lava. Such an environment of high temperature combined with low (near surface) pressure represents, of course, the most favourable condition under which dissociation of calcite would be expected. A small superincumbent load would suffice, however, to prevent dissociation at any temperatures realized in metamorphism.

One further phase, the silicate-carbonate, scawtite (Sc) is recorded in Text-fig. 1. Its composition in the triangle lies to the right of the wollastonite-calcite join, and in the two localities where it is recorded it is apparent that it is a secondary mineral associated with the low temperature changes of retrogressive metamorphism.

(2) *Siliceous (or Silicated) Dolomitic Limestones.*

In the more complex system from which these assemblages are built the recognized thirteen steps and ten mineral indicators are now to be increased, in accordance with the revision of the record of the three component assemblages just given. To the ten indicators are to be added tilleyite and rankinite, and further, the recognition of talc as the earliest step in the decarbonation series of the system (Tilley, 1948). There are therefore thirteen mineral phases while the number of steps are increased to seventeen, effectively two additional with the production of talc and calcite from quartz and dolomite (1), and tremolite from talc, calcite, and quartz (2), while the steps producing tilleyite and rankinite complete the number.

The order of appearance of the three additional phases (*) in relation to the ten originally recognized is readily derived and listed below.

1. talc *
2. tremolite
3. forsterite
4. diopside
5. periclase
6. wollastonite
7. monticellite
8. akermanite
9. tilleyite *
10. spurrite
11. rankinite *
12. merwinite
13. larnite

Further work may yet reveal that additional steps occur ; in particular the possibility should be kept in mind in future study that other silicate-carbonate minerals may exist still unrecognized in some of the complicated assemblages of the high-grade contact zones of basic igneous intrusions.

REFERENCES

AGRELL, S. O., 1950. A gabbro-limestone contact near Camphouse, Ardnamurchan. Abstracts meeting Miner. Soc. (London), 8th June ; also *Amer. Min.*, xxxv, 1080.

BOWEN, N. L., 1940. Progressive metamorphism of siliceous limestone and dolomite. *Journ. Geol.*, xlviii, 225–274.

NOCKOLDS, S. R., 1947. On tilleyite and its associated minerals from Carlingford, Ireland. *Miner. Mag.*, xxviii, 151–8.

TILLEY, C. E., 1942. Tricalcium disilicate (rankinite), a new mineral from Scawt Hill, Co. Antrim. *Miner. Mag.*, xxvi, 190–6.

—— 1947. The gabbro-limestone contact zone of Camas Mòr, Muck, Inverness-shire. *Compt. Rend. Soc. Geol. Finlande*, xx, 97–105.

—— 1948. Earlier stages in the metamorphism of siliceous dolomites. *Miner. Mag.*, xxviii, 272–6.

ZAMBONINI, F., 1935. *Mineralogia Vesuviana*, 2nd edit., by E. Quercigh, Naples, p. 66.

Chalcedony and Flint

By H. G. MIDGLEY (Building Research Station) [1]

(PLATE IX)

ABSTRACT

The possibility of interaction between the alkalies in cement and flint and chalcedony has made it necessary to investigate the constitution of these minerals. It had always been thought that these minerals were a mixture of quartz and opal, but experiments have led to the belief that this is not true and that the minerals are composed of a quartz network with a large number of micropores.

INTRODUCTION

CHALCEDONY and flint have been studied by many workers in the past, usually in relation to their origin and occurrence. Little work has been done on their mineralogical properties, which are likely to prove of technological importance as it has been suggested that the alkalies present in cement may react with either mineral to form sodium silicate gel, and that as a result concrete made from these materials may disintegrate. Their constitution has been investigated at the Building Research Station and some of the results are reported in this paper.

It has usually been accepted that chalcedony and flint contain about 1 per cent of combined water, and that the two minerals are composed of an intimate mixture of quartz and opal. Donnay (1936) calculated that chalcedony consists of some 10 per cent opal and 90 per cent quartz. He determined these quantities by taking into account the water contents of chalcedony and opal and the difference in density between quartz and chalcedony. Using the refractive indices of quartz and opal, he calculated the refractive indices of a mixture of 10 per cent opal and 90 per cent quartz, and the results from these calculations agreed with the experimental results for natural chalcedony.

X-ray powder photographs of chalcedony and flint appeared to be identical with those of quartz, and it was assumed that the main opal band was hidden by the strong 4·26A line of quartz.

Investigations on a large number of specimens of chalcedony and flint have lead the author to doubt the validity of the quartz-opal admixture theory, and the results of these investigations are reported below.

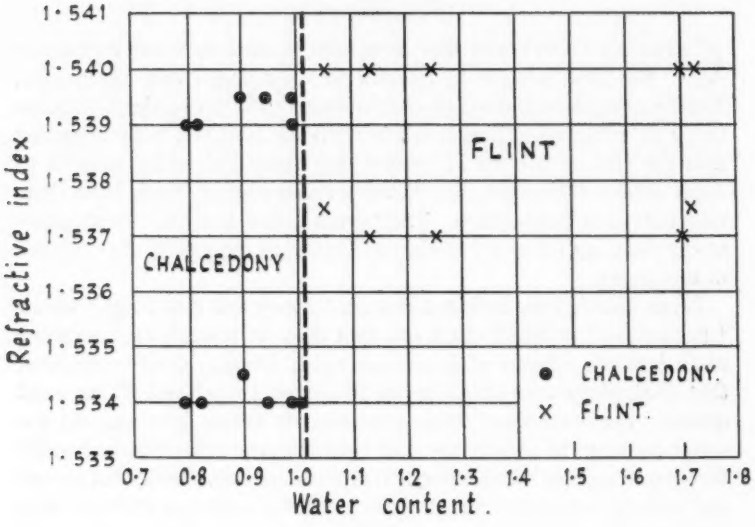
OPTICAL PROPERTIES

The refractive indices of a number of specimens of chalcedony and flint were measured by the immersion method in sodium light with an accuracy of $\pm 0{\cdot}001$.

Chalcedony has α 1·534, γ 1·539, and flint α 1·537, γ 1·540.

[1] Published by permission of the Director of Building Research.

It will be seen that there is very little difference between the two minerals, but when the refractive indices of specimens were plotted against the water content, as determined by loss at 1,000° C., the difference was significant (Text-fig. 1). It was found that there was no continuous variation of refractive index with water content, but that those specimens with less than 1·0 per cent water had refractive indices α 1·534, γ 1·539, and with more than 1·0 per cent, α 1·537, γ 1·540. This suggests a means of dividing chalcedony and flint by mineralogical definition and not, as is more usual, by mode of occurrence, i.e. flint,



TEXT-FIG. 1

more than 1·0 per cent water, α 1·537, γ 1·540; chalcedony, less than 1·0 per cent water, α 1·534, γ 1·539.

X-RAY DIFFRACTION

Since Washburn and Navais (1922) first reported it, it has been known that chalcedony and flint gave X-ray powder diffraction photographs which appeared to be identical with those given by quartz (Plate IX, fig. 1 *a*, *b*, and *c*).

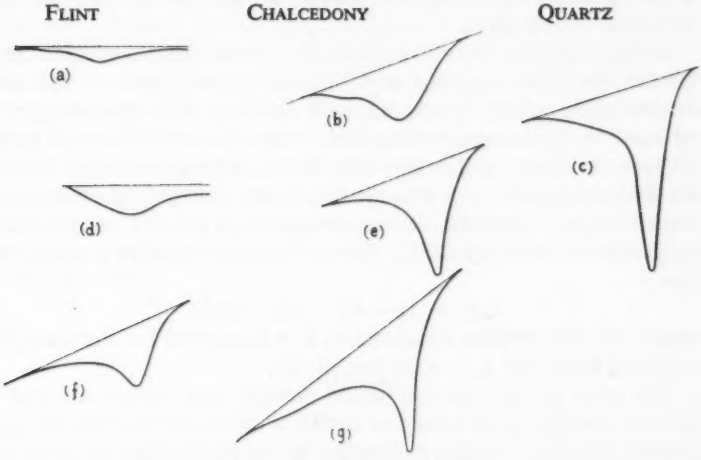
Samples of opal all give a broad band at about 4.2A. In certain opal specimens other lines may also be present; these can be indexed as due to cristobalite. The band, which is characteristic of opal, is very near the 4·26A strong line of quartz, and so it was thought that if opal were present in flint or chalcedony the band might have been obscured,

although it should have been possible to detect it by means of the relative intensity compared with other quartz lines.

X-ray diffraction photographs of the critical region around 4·2A were taken on an experimental semi-focusing camera constructed by my colleague, Dr. E. Aruja (to whom I am indebted for these photographs).

Photographs obtained from mixtures of opal and quartz and from opal, chalcedony, and flint are shown in Plate IX, fig. 2.

The band due to opal can be seen clearly at one side of the strong



TEXT-FIG. 2

quartz line and in the 10 per cent opal 90 per cent quartz mixture it is still easily seen. No corresponding line can be seen in the spectra of chalcedony and flint and a microphotometer has failed to detect any trace of it.

From the X-ray evidence it would appear that chalcedony and flint are not composed of a mixture of quartz and opal, but consist almost entirely of quartz. From the broadening of the quartz lines it may also be concluded that the quartz crystallites in flint and chalcedony are very small.

DIFFERENTIAL THERMAL ANALYSIS

Differential thermal analysis curves were carried out on samples of chalcedony, flint, and quartz of equal weight. The results in the region of the α-β quartz inversion at 573° C. are given in Text-fig. 2 *a*, *b*, *c*. If, as Berklehamer (1944) suggests, the area under the break is proportional to the quantity of quartz present, then the quantity of quartz in flint is about 12 per cent and in chalcedony 65 per cent, or if we take

the height of the break, as suggested by Grimshaw, Westerman, and Roberts (1948), then the quantity of quartz in flint is 10 per cent and in chalcedony 35 per cent. These results are very different from those obtained by Donnay (1) by calculations from water content, density and refractive indices. Differential thermal analysis curves were also obtained on samples of chalcedony and flint which had been heated at 1,000° C. for sixteen hours (Text-fig. 2 *d*, *e*) and fifty-six hours (Text-fig. 2 *f*, *g*). All the water should have been removed by this treatment. Once again the α–β quartz inversions are not equal to that given by an equivalent mass of quartz, but the size of the break has increased with heating.

At first sight the differential thermal analysis results appear to contradict the X-ray evidence that the major constituent of flint and chalcedony is quartz. The explanation probably lies in the minute size of the crystallites in which the quartz occurs. Mample (1940) has made a theoretical study of the effect of particle size on a reaction spreading from nuclei and shows that for comparatively large particles there is no induction period and the reaction proceeds at a fast rate (proportional to the fourth power of time) ; for very small particles he suggests the law :—

$$l_n (1 - \alpha) = k(t - t_o) + \text{const.}$$

where α is the fraction transformed, k is a constant for the reaction, t elapsed time, and t_o an induction period.

The effect of an induction period varying with particle size and a general slowing up of inversion would be to spread out the thermal analysis break and reduce its height ; in the extreme case it would be almost impossible to say where the break begins or ends, and the measurement of area would be impracticable. The increase in size of the break, with time of treatment at 1,000° C., would then be attributed to crystal growth.

Surface Area

The surface area of specimens of chalcedony and flint was determined by the nitrogen adsorbtion method of Brunaur, Emmett, and Teller (1945). The surface measured is that available to the nitrogen molecule, and is generally considered to include internal structures and defects. Coarse fractions, 52–100 B.S. Sieve, were used, so that the external surface would be negligible in relation to the internal surfaces. The results are given in Table 1.

Table 1

Mineral.	*Surface Area, sq. cm./gm.*
Chalcedony . .	4,300
Flint . . .	2,200
Quartz . . .	0
Opal . . .	400,000

The internal surface area of chalcedony and flint could be due to two different causes : (*a*) to small micro-pores in the structure, or (*b*) to the opal content in a quartz-opal mixture. If the surface area is to be accounted for by the presence of opal then the quantity needed is, for chalcedony 1·0 per cent and for flint 0·5 per cent. The results once again are not in agreement with those calculated from water content or optical properties.

Thus it would appear more reasonable to suppose that the surface area of chalcedony and flint is due to a large number of micro-pores. It is of some interest to make a rough estimate of the size of the pores. The water content of chalcedony is about 0·8 per cent, and if it be assumed that the specific volume of this adsorbed water is the same as that for free water, then the volume of pores is about 0·8 c.c. for 100 gm. of chalcedony. The specific surface per unit volume of pore space is therefore 430,000 ÷ 0·8, or 537,500 sq. cm. per c.c. If the pores are cylindrical their specific surface per unit volume $= 2/r$, whence r (radius of the pore) is about 1×10^{-6} cm. Similarly for flint r is about 14×10^{-6} cm. The existence of pores of approximately this size has been reported by Folk and Weaver (1950) in an electron microscope study of chert.

Conclusions

The main point to be decided is whether chalcedony and flint contain opal. The X-ray evidence proves conclusively that the quantity of opal, if it is present, must be considerably less than 10 per cent. On the other hand, to account for the accepted values of density and refractive index, more than 10 per cent of opal would be required. Specific surface measurements point to the existence of pores varying from 0·02 to 0·28 microns in diameter, and pores of 0·10 microns diameter have been detected by electron microscopy ; opal itself has such a high internal surface that it cannot be postulated that the specific surface of flint and chalcedony is due to admixed opal.

The presence of the large number of small micropores, filled with either water or air, or a mixture, would account for the apparent lowering of the refractive indices of chalcedony and flints, since in the micro size structures, where the individual discontinuities are of a size approximating to the wavelength of light, they will interfere and so reduce the apparent refractive index.

The only evidence which appears to contradict the theory that flint and chalcedony are composed of a microporous mass of silica is that obtained from differential thermal analysis ; these results are, however, satisfactorily accounted for by the small size of the quartz crystallites.

REFERENCES

BERKLEHAMER, L. H., 1944, Differential Thermal Analysis of quartz. *Bureau of Mines, U.S.A., Report* 3763.

BRUNAUER, S., 1945. *The Adsorption of Gases and Vapours.* Princeton.

DONNAY, J. D. H., 1936. Le birefringence de forme dans la chalcedonie. *Ann. Soc. Geol. Belge.*, lix, B289.

FOLK, R. L., and WEAVER, C. E., 1950. Surface Features of Chert as studied by the Electron Microscope. *Abs. of* 31*st Ann. Meeting, Min. Soc. Amer.*, 10.

GRIMSHAW, R. W., WESTERMAN, A., and ROBERTS, A. L., 1948. Thermal Effects accompanying the Inversion of Silica. *Trans. Brit. Cer. Soc.*, xliii, 1.

MAMPEL, K. L., 1940. Time v. amount of reaction formulas for heterogeneous reactions at the phase boundaries of solids. *Zeit. Phys. Chem.*, clxxxvii, 43.

WASHBURN, E. W., and NAVAIS, L., 1922. Relation of chalcedony to other forms of silica. *Proc. Nat. Acad. Sci.*, viii, 1.

EXPLANATION OF PLATE IX

FIG. 1.—*a*, quartz; *b*, chalcedony; *c*, flint; *d*, opal.

FIG. 2.—*a*, opal; *b*, 50 opal, 50 quartz; *c*, 10 opal, 90 quartz; *d*, chalcedony; *e*, flint.

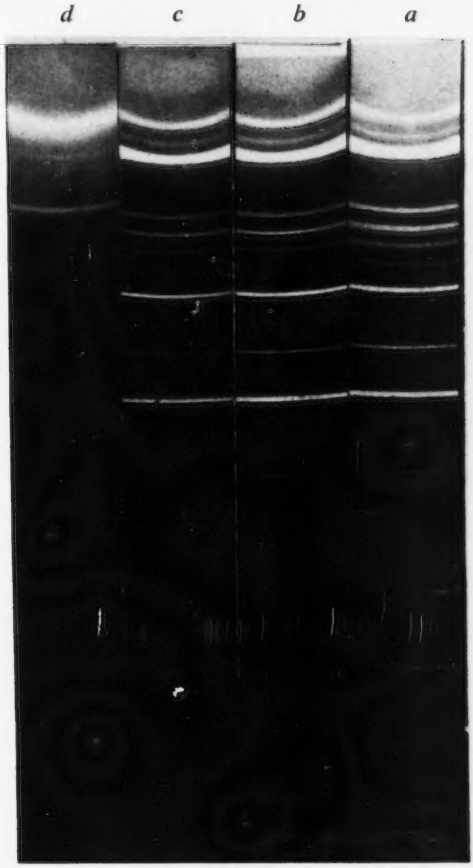


FIG. 1.

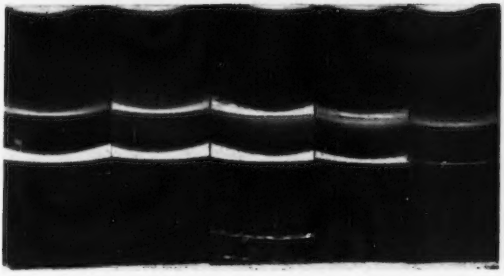


FIG. 2.

X-RAY POWDER DIFFRACTION PHOTOGRAPHS OF CHALCEDONY, FLINT, ETC.

A Note on the Development of Large Garnets in Sutherland Migmatites

By T. G. K. CHARLU

With an

ADDENDUM ON ADIRONDACK GIANT GARNETS

By H. H. READ

(PLATE X)

ABSTRACT

In the outer zone of the Sutherland Migmatite Complex, four-inch garnets are developed in " veins " in garnetiferous rocks which, adjacent to the " veins ", are devoid of garnet. The redistribution of material has been brought about by activity along certain privileged paths. Comparison is made with the gigantic 3-ft. garnets of the Adirondacks.

INTRODUCTION

IN the Borgie area between Bettyhill and Tongue, on the north coast of Sutherland, the rocks of the Moine Series lie on the outer margin of the great Sutherland migmatite complex described by Read (1931) and Cheng (1943). With the exception of true psammitic types all varieties of the Moine rocks and also the metamorphic greenstone derivatives of basic intrusions found in them show widespread but small garnets. Locally, however, garnet crystals reach a size of three or four inches across. It is the purpose of this note to give an account of the occurrence and genesis of these large garnets. That they are the product of movement of material in metamorphic and migmatitic processes can be demonstrated largely by straightforward field-studies.

In addition to his own collection the writer has had the advantage of studying material collected and described by Dr. Cheng from the Bettyhill region immediately to the east of Borgie. He is indebted to Professor H. H. Read for guidance throughout his work in Sutherland.

THE GEOLOGICAL SETTING

The Moine rocks of the Borgie area are mainly semipelitic and siliceous granulites, together with numerous bands of garnetiferous pelitic schist. Intimately associated with these types, especially in the western part of the area, are evenly-striped rocks characterized by abundant hornblende—the Durcha Hornblendic Rocks of Read. Small basic and ultrabasic intrusives, now metamorphosed into amphibolites, eclogites, and serpentines, are common in the various sedimentogenous Moine types. All the rocks of the Borgie area are modified as the result of the development of abundant veins, sheets, patches, and dykes of pegmatite. Thick pegmatite sheets are especially common in a zone

traceable for five miles from Apigill to Torrisdale. The area as a whole forms a part of the " zone of veins " of the larger migmatite complex farther south.

For the special purpose of this account, two rock-types are mainly concerned. Under conditions of normal development these are a group of sedimentogenous pelitic rocks, *garnet-mica-hornblende-gneisses*, and a group of metamorphosed basic igneous rocks, *garnet-amphibolites*.

Garnet-mica-hornblende-gneisses.—These rocks are similar to the pelitic schists and gneisses with which they are interbedded, but they are noteworthy in containing accessory hornblende. They occur as thin parallel bands and are particularly well exposed along the north-western margin of Thorrisdail Bay. Here they are veined and lensed by pegmatites. Felspar augen are developed in the more modified varieties which then pass into augen-migmatites. In thin section the gneisses are seen to consist of parallel stripes of greenish-brown biotite plates and pale green hornblende prisms set in a granulitic base of quartz and felspars, with abundant grains of sphene arranged parallel to the foliation ; accessory components are iron-ore, epidote, and brown orthite. The colourless folia of the gneiss consist of quartz and acid oligoclase, often sericitized. Large plates of orthoclase partially replace the plagioclase with the development of antiperthitic intergrowths. Garnet occurs in small embryonic and fragmentary grains in the felspathic areas and is evenly distributed throughout the rock.

Garnet-amphibolites.—The poorly-foliated amphibolites occur in concordant lenticular masses varying greatly in size. All show some indications of later soak, but types only slightly modified by such processes are the most common. These rocks are compact and homogeneous and are almost always speckled with tiny grains of pink garnet and white felspar evenly distributed in the dark amphibole background. In thin section the components are seen to be hornblende, plagioclase, garnet, and quartz, with accessories. Hornblende, the dominant component, occurs in subhedral crystals and has a pleochroic scheme of Z bluish green, Y pale green, X nearly colourless. The plagioclase, andesine in composition, forms irregular plates and is usually intensely sericitized. It often encloses small grains of hornblende that show the same optical orientation as nearby larger crystals. Garnet shows a variety of forms, and ranges from small grains and larger skeletal groups to subhedral and euhedral crystals. Some of the garnet grains are solid, others are sieved by blebs and irregular grains of plagioclase. The garnet is evenly spread through the rock, occurring for the most part in the plagioclase areas, though deriving its material from both mafic and felspathic sources. The quartz forms small grains that are often collected into patches. Along certain channels the hornblende has been converted into a brown biotite. Other accessory components

are iron-ore in spongy patches, grains of sphene, and less abundant rutile and apatite.

The Large Garnets

The development of large garnets in the *garnet-mica-hornblende-gneiss* is well displayed along Thorrisdail Bay, especially on its southern shore, where individuals of garnet reach a diameter of 3 inches. It is clear in the field that their production is related to soaking and " veining " processes. Thus, it is observed that extra-large garnets appear where quartzo-felspathic migmatitic material is abundant. A " vein " of such material some 8 inches wide can be traced from a pegmatite body for a distance of some 15 feet ; at intervals along the " vein " there appear large garnets, of average size 3 by 1½ inches, enclosed in the acid material. It is noteworthy that *no garnets occur in the gneisses adjacent to the " vein " whereas they are evenly distributed in the main portions of the gneiss.* Immediately at the contact of the " vein " and the gneiss large hornblende crystals are also conspicuous. Within a 2-ft. length of the " vein " seventy-five euhedral hornblende crystals and twenty large garnets were counted. The acid " veins " are composed of large oligoclase plates often with replacing orthoclase rims and " film and patch " antiperthitic intergrowths. In slices, large plates of sieved hornblende, about 10 by 8 mm. in size, with Z deep bluish-green, are seen to be developed along narrow " veinlets " of oligoclase and quartz ; myrmekite intergrowths are common.

The large garnets exhibit a remarkable micropegmatitic intergrowth with quartz (Plate X), an intergrowth also shown on a smaller scale by those which occur in the amphibolites that are described immediately. The quartz areas in the intergrowth do not show uniform optical orientation ; indeed, each compartment of quartz extinguishes in a position different from those of its neighbours. Replacement of garnet by quartz is therefore excluded. The garnet of these intergrowths is in slices pale yellowish in colour, and does not differ microscopically from that of the gneisses. The large garnets enclose small prisms of hornblende, biotite flakes, and grains of iron-ore and sphene. Mica flakes sweeping round the garnet are curved and often show signs of modification due to pressure exerted by the growing garnet.

Intergrowths of garnet with quartz or felspar that appear to be similar in form to those from Borgie have been described by Heddle (1878), Becke (1882), Lacroix (1889), and Holland (1896).

The lenticular bodies of *amphibolite* that occur in the pelitic and semipelitic rocks forming the ridge immediately west of the River Naver supply excellent examples of the development of large garnets. The normal type of amphibolite here has already been described.

Where, however, the amphibolite shows conspicuous soaking or " veining ", a redistribution of material over a considerable area is apparent. In such " veined " rocks the foliation-planes are often studded with large claret-coloured garnets up to 3 inches across. Each garnet is surrounded by a quartzo-felspathic sheath and forms a node on a ramifying stringer. Similar phenomena are seen at the margins of the amphibolite lenses and along obvious channels of permeation. Additional evidence of migmatitic soak is given by the development of biotite as sheaths to garnet and hornblende crystals, and as coatings along foliation-planes of the amphibolite. Many of the quartzo-felspathic patches and stringers can be related to pegmatite " veins ".

Especially good examples of the growth of large garnets in garnet-amphibolite are exposed on Naver Rock. Adjacent to the contacts with pegmatite " veins " the amphibolites that elsewhere show evenly distributed garnets become free from this mineral, and at the same time they become coarser in grain. Along the obvious channels of major permeation and " veining " garnet individuals of a deep pink colour and reaching 4 inches in diameter are developed. It is clear that a redistribution of material adjacent to the channels of soaking has taken place. Such channels can be traced over considerable distances. The final stage in the migmatitization of the amphibolite is shown by very coarse rocks with large garnet aggregates in quartzo-felspathic streaks and patches.

In certain occurrences large garnets are produced at the contacts of amphibolites and sedimentogenous country-rocks. For instance, such garnets occur at the contact of an amphibolite and semipelitic schist at Point 504 on Naver Rock. Both rocks are free from garnet at the contact, but away from it are abundantly garnetiferous. It is clear that the large garnets have drawn their material from both rocks. Again, another amphibolite at Point 552 on Naver Rock is in contact with a pelitic band ; along the contact large garnets are abundant. Adjacent to this junction no obvious " veining " is seen but permeation is clearly displayed. It appears once again that the large garnets arise by soak and redistribution about a channel and have derived their material from rocks on both sides of the contact.

Conclusion

From this field-evidence certain conclusions concerning the genesis of the large garnets are warranted. Such garnets are developed either in " acid veins " in garnetiferous rocks or along contacts between different kinds of such rocks. Adjacent to the " veins " or contacts the rocks are devoid of garnet and it can be suggested, pending a detailed study of the chemical compositions of the country-rocks and contact-zones of the " veins ", that the garnet substance from the

impoverished zones has been concentrated in the " vein " or along the contact. This redistribution of material is brought about by activity along certain privileged bands, paths, or channels. The garnet substance has drained, as it were, towards the contact or into the channel or into the portion of the privileged band that now appears as a " vein "—the operation proceeding by permeation, diffusion, and segregation. This note is to record the evidence indicating the marked mobility of material even in the " Zone of Veins " of a migmatite complex.

Addendum on Adirondack Giant Garnets

The foregoing note was prepared by Dr. Charlu in 1948. It was laid aside because I had had the privilege of examining the magnificent specimens of gigantic garnets from the Adirondacks exhibited in the Department of Geology, Columbia University, New York, and had become aware that a detailed study of them was in progress. The main results of this study are now available in an exhaustive paper by S. B. Levin (1950). It is the purpose of this addendum to present a summary of Levin's results in so far as they concern the Sutherland topic and to make sporadic comments upon them.

Levin deals in particular with the garnet deposits mined for abrasive at the Barton Mine, Gore Mountain. Here garnets, 3 feet across and sheathed by hornblende shells inches in width, occur at the contact of metagabbro and syenite. (All Adirondack rock-names and processes given in this addendum are those used by Levin.) The Barton garnet-ore is interpreted as due to progressive recrystallization and growth from embryonic regional garnets during the peripheral metamorphism of the gabbro by the intrusive syenite magma.

The account of the regional setting of the garnetiferous rocks is of interest to non-American geologists because there is a more or less evident tendency to allow a greater degree of migmatization at various stages in Adirondack geological history. Migmatites are mentioned as making part of the Grenville Series that form the country-rocks for the Anorthosite-gabbro Series, this now largely in a metamorphic condition. The later Syenite-granite Series includes " hybrid facies or migmatites ". I make the suggestion with humility that it might be profitable to regard Adirondack geology less from the magmatic and more from the metamorphic-migmatitic or plutonic standpoint.

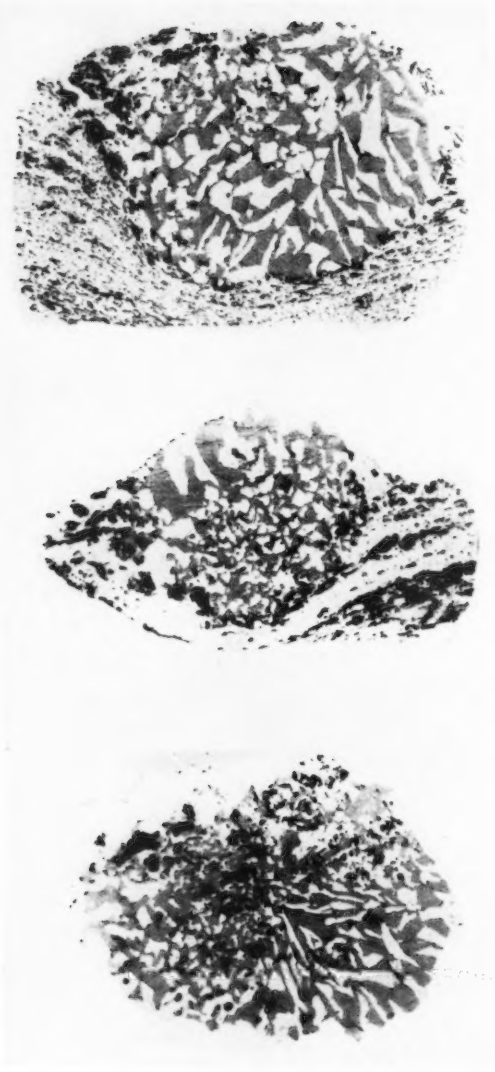
Regionally, the garnets are more prominent in the more metamorphic and more basic types, such as metagabbro, amphibolite, and gabbroic anorthosite, than in members of the Syenite-granite Series. One type of occurrence of large garnets mentioned by Levin shows considerable resemblance to the Sutherland examples in its geological relationships. In Grenville mixed gneisses (possibly migmatites) huge garnets, up to 3 feet across and with or without hornblende shells, occur in

dark hornblende-biotite-felspar-gneisses and dark amphibolite-gneisses, generally near syenite or syenitic gneiss.

As already noted the Barton deposit occurs at the contact between gabbro and syenite along the periphery of an outlier of garnetiferous anorthosite and metagabbro. The syenite produces " hybrids " near the contact that are abundantly garnetiferous. Some hybrids are interpreted as consisting of xenolithic garnet and hornblende in a felspathic matrix.

An important point that Levin makes is that the garnets constitute a single continuous series having a relatively limited compositional range in all facies of rocks. The stages of garnet formation distinguished are : (1) the early stages of embryonic garnets in the anorthosite-gabbro facies are marked " by the emplacement of the garnet (being) accomplished wholly at the volumetric expense of the plagioclase "—a statement recalling similar features in the Sutherland rocks ; (2) a more advanced stage is clearly related to the syenite contact, sieved irregular garnets being formed by " grain-growth recrystallization in which the substance of the more widely scattered and generally finer grained corona garnet contributed and was consumed in the growth of larger but fewer garnet individuals "—the total amount of garnet in the rocks remaining unchanged ; (3) the next stage is marked by the growth of megascopic non-poikillitic garnet porphyroblasts, set well apart, again apparently with no reduction in the total amount of garnet in the rocks ; (4) in the final stage, giant garnets, some weighing a ton and a half each and surrounded by a thick hornblende shell, are formed in a matrix of hornblende and plagioclase. Analyses show that no significant difference in bulk composition of the facies containing these various kinds of garnets and constituting the series up to the contact can be detected. " The garnet ore is simply a highly reconstituted facies of the gabbro."

The origin of the Barton garnet deposits has been a matter for considerable discussion among Adirondack geologists. Miller's original view was that they were due to the modification of Grenville inclusions, but later he invoked a double contact-metamorphism ; Balk considered them to be primary magmatic segregations ; Buddington ascribed them to post-syenite regional metamorphism, the large hornblende-rimmed garnets arising by the agency of solutions working under more favourable conditions at the contacts of two different rocks. Levin's proposed hypothesis is that the growth of garnet porphyroblasts in the Anorthosite-gabbro Series was induced by the rise and action of syenite magma, especially so along intrusive contacts ; this action was favoured by the suitable composition of the gabbro, but the real controlling feature was the presence of pre-existing corona garnet. The most advanced stages in the progressive recrystallization of this



LARGE GARNETS WITH INTERGROWN QUARTZ, SUTHERLAND.

corona garnet are seen near the contact where metamorphic conditions were most intensive. The hornblende shell is produced by the growth of the garnets—" the larger the garnet grows the more rim it accumulates ". We see the same thing happening on a very small scale in the Sutherland rocks (Plate X).

No matter how different the nomenclature of the rocks of the two areas may be, it appears that similar processes of mobility of material induced by soaking have operated in the Adirondacks and in Sutherland.

REFERENCES

BECKE, F., 1882. Die Gneissformation des wiederösterreichischen Waldviertels. *Tscher. Min. Pet. Mitt.*, iv, 406.

CHENG, Y. C., 1943. The Migmatite Area around Bettyhill, Sutherland. *Quart. Journ. Geol. Soc.*, xcix, 107.

HEDDLE, M. F., 1878. Chapters on the mineralogy of Scotland, Chapter 3—The garnets. *Miner. Mag.*, ii, 230.

HOLLAND, T. H., 1896. On the origin and growth of garnets and of their micropegmatite intergrowths in pyroxene rocks. *Rec. Geol. Surv. India*, xxix, pt. 1, 30.

LACROIX, A., 1889. Contributions à l'étude des gneiss à pyroxène et des roches à wernérite. *Bull. Soc. Min. Fr.*, xii, 317.

LEVIN, S. B., 1950. Genesis of some Adirondack garnet deposits. *Bull. Geol. Soc. Amer.*, lxi, 519.

READ, H. H., 1931. Geology of Central Sutherland. *Mem. Geol. Surv. Scotland.*

EXPLANATION OF PLATE X

Thin sections of garnet-quartz micropegmatite in soak " veins " in garnet-mica-hornblende-gneiss, Thorrisdail Bay, Borgie, Sutherland (twice natural size).

Importance of the "Tectonical" Model Theory

By T. J. VAN DER ZEE

ABSTRACT

Neglect of the oldest and most useful theory of scale models in geology. Its fundamental psychological value for a correct mental picture of the earth's larger aspects.

The exact theory made more comprehensible. Its application in the domain of experimental tectonics improved upon.

INTRODUCTION

EVERY geologist has to make reduced and accelerated images of the larger and more slowly changing aspects of the earth. On account of his training these conceptions are geometrically—and also kinematically—more or less correct. But in most cases such mental pictures are as yet "unsubstantial", or implicate erroneous values for the material constants. In particular, an image of the earth's crust tends to be conceived with far too much strength by vague association with, for instance, hard rocks or terrestrial globes made of cardboard.

This lack of insight is perhaps best supplied by a theory of scale models which has been developed in the field of experimental tectonics. It enables anyone acquainted with the rudiments of mechanics to get in touch with the whole earth, as it were, by reducing it in imagination to a model which he holds in his hands.

The theory is here called the tectonical model theory, as it may be distinguished, for example, from the less intelligible system of rules employed in hydrodynamics, while it may also be specified as the oldest and most useful of similar exact theories in tectonical geology.

It was introduced by Morath (1913), who built on results of Helmholz. However, through a rather complicated argumentation and a few errors, never corrected, his important dissertation seems to have been insufficiently understood at the time, and was soon forgotten. Apparently the same lot fell to most of the comparatively few similar treatises in geological literature.

Indeed, authors often worked independently from one another, arriving at different conclusions. Moreover, various omissions in these discussions, which to my knowledge were never set right, may have led to misunderstandings, preventing a more general application of the tectonical model theory. For geologists, the main importance of these theories seems to have been their bearing on tectonical experiments, the results of which hardly ever succeeded in arousing much interest.

It appears that Hubbert (1937, 1945) was the last to contribute to the theory. His argument is simpler than that of Morath. The first of his two excellent articles, however, covers a wider field than the tectonical model theory alone, while the second approaches the

problem of determining the properties of a correct tectonical model from a more general and algebraic point of view, which makes it difficult reading for the average geologist.

Morath has pointed out that for two dynamically similar bodies (i.e. a true model and its original), the formula for the ratio of any mechanical quantity can be found immediately from the formula for its dimension (which expresses the relation between the quantity in question and the three fundamental quantities, mass, length, and time).

Hubbert merely mentioned the possibility of a demonstration. Therefore it may be emphasized that such a demonstration involves the easiest and most congruous method for determining all the desired reduction factors. To be sure, Hubbert made use of this method, but not consistently.

The Tectonical Model Theory

For a simple explanation of the tectonical model theory, the essentials of the theory are here dealt with and a somewhat elaborated table is added, arranged in such a way as to lead from the simpler types of dimensions and ratios to those less comprehensible (p. 196). The table may elucidate a few points. For the derivation of dimensions which are not self-evident anyone who is versed in mechanics may be consulted.

Two different bodies may show a similarity which is geometric, kinematic, or dynamic. For a kinematic similarity there must be proportional lapses of time besides geometrical likeness. For dynamic similarity, moreover, a corresponding distribution of mass.

The second and third columns of the table give the dimensions of several physical quantities, and the ratios between their numerical values in a true model and its original. By making use of the laws of classical mechanics the dimensional formulae can be found easily from the definitions of the quantities in question. The ratios can then be arrived at by simple division.

In actually existing tectonical models the ratio of gravity acceleration ($l.t^{-2}$) is equal to unity. Under the circumstances $l.t^{-2} = 1$, or $l = t^2$, most experiments would require far too much time or would have to be carried out on much too small a scale. Morath, however, pointed out that for slow movements all accelerations due to inertial forces may be neglected. Their ratios may therefore also be taken equal to unity. Under such quasi-static conditions the ratios of quantities, related to an acceleration, can be divided by the factor $l.t^{-2}$ (this factor being equal to unity), after which the ratios l and t may be considered as being independent of each other. We then get the ratios in the fourth column of the table.

In calculations it is more practical to use the ratio of density than that of mass, as appears in the fifth column. In the sixth column the

numerical values of these last ratios are given for a model of earth crust of plausible length, time, and density scale.

Some Applications of the Theory

A geological representation, geometrically correct, will gain much if a proper strength is also visualized. The easiest way of doing so is perhaps the one indicated by Morath, who represented the crushing strength of a certain material by the greatest possible height of an actual pillar made of the substance in question. One has only to multiply this height in the original with the reduction factor l to illustrate the correct strength in the model.

Just as when studying or making a map one can take account of a third dimension and make relief models to promote this habit, so one can also imagine and show a correctly reduced strength for a geological formation with regard to the scale of the map. Relief models for the special purpose of demonstrating suitable strengths are readily fabricated. For that matter no great difficulties are encountered in making moving models, showing a correctly reduced viscosity.

Another application of the tectonical model theory enables us to appreciate the value of tectonical model experiments. In fact, the theory was developed by Morath only for this purpose. However, he formed two obvious but important misconceptions which are also encountered in the work of Hubbert. The first implies that geometrical or kinematical similarity would only be possible in a model which is also dynamically similar. The other suggests that such an entirely correct model can actually be made not only with a proper strength or viscosity, but with both of these as well as with the right compressibility, atmospheric pressure, etc. It appears, therefore, that tectonical model experimentation and perhaps its purposes, too, are not yet rightly appreciated in their merits and shortcomings.

Here, three categories of tectonical model experiments are distinguished. The first of these would be performed to obtain supplements of the as yet incomplete pictures of structures or their development in nature. Although such experiments must merely aim at a geometrical or kinematical likeness, experience has shown that in general these models give greater satisfaction when they are more dynamically correct. Even then, a supposed geometric or kinematic similarity can only guide but never replace the field geologist's observations. Well-known examples of this kind of experimental tectonics are those given by H. Cloos (1939), which helped to unravel the structure of rift valleys.

The second category (which may be considered as a transition to the third) would be executed with models, showing a dynamical similarity which is qualitatively correct, to gain a clearer understanding of

TABLE.—DIMENSIONS OF SOME QUANTITIES AND THEIR RATIOS IN TWO DYNAMICALLY SIMILAR BODIES

Quantity	Dimension	Ratio between two dynamically similar bodies	The same, but with slow quasi-static movements and with equal gravity	Last ratio expressed in terms of d, l, and t	Example of plausible length, time and density scale
Length	L	l	l	l	4.10^{-7}
Volume	L^3	l^3	l^3	l^3	64.10^{-21}
Angle	L°	1	1	1	1
Strain	L°	1	1	1	1
Mass	M	m	m	$d.l^3$	$3^{-1}.64.10^{-21}$
Density	$M.L^{-3}$	$m.l^{-3}$	$m.l^{-3}$	d	3^{-1}
Time	T	t	t	t	10^{-13}
Velocity	$L.T^{-1}$	$l.t^{-1}$	$l.t^{-1}$	$l.t^{-1}$	4.10^5
Acceleration	$L.T.^{-2}$	$l.t^{-2}$	1	1	1
Force	$M.L.T^{-2}$	$m.l.t^{-2}$	m	$d.l^3$	$3^{-1}.64.10^{-21}$
Stress, strength, elasticity modulus	$M.L.^{-1}T^{-2}$	$m.l^{-1}.t^{-2}$	$m.l^{-2}$	$d.l$	$3^{-1}.4.10^{-7}$
Compressibility	$M^{-1}.L.T^2$	$m^{-1}.l.t^2$	$m^{-1}.l^2$	$d^{-1}.l^{-1}$	$3.4^{-1}.10^7$
Viscosity	$M.L^{-1}.T^{-1}$	$m.l^{-1}.t^{-1}$	$m.l^{-2}.t$	$d.l.t$	$3^{-1}.4.10^{-19}$
Gravitational constant	$M^{-1}.L.^3T^{-2}$	$m^{-1}.l^3t^{-2}$	$m^{-1}.l^2$	$d^{-1}.l^{-1}$	$3.4^{-1}.10^7$

tectonical relations and dynamical effects. Thus, Nettleton (1934) elucidated the isostatic rise of saltdomes, using models in which the salt was represented by oil (density 1·0) and the sedimentary cover by syrup (density 1·4).

Through the third category of model experiments and by making use of the tectonical model theory one can compute a strength or (equivalent-) viscosity in nature when, respectively, a certain geometric or kinematic resemblance has been established, and when the causative forces are gravitational. For instance, Kuenen (1937) made several models of the earth's crust, observing the maximal relief they were to bear. The strength of one of these models may be taken to have been 0·2–0·4 g./cm.². With a length scale of 1 : 2,500,000 and a density ratio of 1 : 3 the ratio of strength for this particular model would be 1 : 7,500,000. From which it would follow that the strength of the earth's crust is $7{,}500{,}000 \times 0{\cdot}2\text{–}0{\cdot}4\ \text{g/cm}^2 = 1{,}500\text{–}3{,}000\ \text{kg/cm}^2$; a value one quite well might believe to represent the real strength of a granitic layer.

REFERENCES

Cloos, H., 1939. Hebung — Spaltung — Vulkanismus. *Geol. Rundschau*, xxx, 405–527.

Hubbert, M. K., 1937. Theory of scale models as applied to the study of geologic structures. *Bull. Geol. Soc. Amer.*, xlviii, 1459–1520.

—— 1945. Strength of the earth. *Bull. Amer. Assoc. Petrol. Geol.*, xxix, 1630–1653.

Kuenen, Ph. H., 1937. The negative isostatic anomalies in the East Indies. *Leid. Geol. Meded.*, viii, 169–214.

Morath, O., 1913. *Theoretische Grundlagen für die Konstruktion geologischer Modelle*. Dissertation, Freiburg i. Br.

Nettleton, L. L., 1934. Fluid mechanics of salt domes. *Bull. Amer. Assoc. Petrol. Geol.*, xviii, 1175–1204.

The Place of the Trimingham and Norwich Chalk in the Campanian-Maestrichtian Succession [1]

By J. A. JELETZKY (Geological Survey of Canada, Ottawa)

ABSTRACT

The Maestrichtian is considered an independent stage younger than and equal in rank to the Senonian stage; in its type-area it includes, besides the Maestricht Tuff, such older formations as the Chalk of Ciply and of Spiennes, the Kunrade Limestone, upper beds of the Gulpen Chalk, and even some part of the Hervian Greensands. The zone of *Pachydiscus egertoni* forms the base of the Maestrichtian stage.

In its type locality the Campanian stage includes the zone of *Bostrychoceras polyplocum*; at the same time its uppermost beds are at any rate not older than the uppermost beds of the Senonian stage in its type area. The zone of *B. polyplocum* thus forms a part of the Senonian stage.

The true *Belemnella lanceolata* (Schloth.) is restricted to the Trimingham Chalk. *Belemnitella* ex. gr. *mucronata* (including "*Belemnites lanceolatus*" von Sharpe and Blackmore *non* Schloth.) are, on the contrary, all but confined to the Norwich Chalk and older beds of the English Upper Chalk. Accordingly, a new zonal name "Zone of *Belemnella lanceolata*" is recommended for the Trimingham Chalk, and the zone of *Belemnitella mucronata* should, in the opinion of the writer, be restricted to beds older than the Trimingham Chalk.

The Trimingham Chalk is assigned to the Lower Maestrichtian, while the Norwich Chalk represents the Upper Campanian (including the *B. polyplocum* zone).

1. INTRODUCTION AND ACKNOWLEDGMENTS

WHEN dealing recently with the correlation of the younger boreal Upper Cretaceous deposits of northern Eurasia and their belemnoid faunas, the writer (Jeletzky, 1948*a*, 1948*b*) was unable to consider the Upper Cretaceous deposits of Great Britain. A few suggestions concerning the assumed close affinity of British Upper Cretaceous belemnoid faunas with those of north-west Europe, Poland, and Russia included in these papers (Jeletzky, 1948*a*, pp. 338, 346; 1948*b*, p. 590), and the investigation of the validity of certain British belemnoid names were based exclusively on the study of the literature and on general palaeozoogeographical considerations.

This paper results from a study of the *Belemnittela*-like forms from the Norwich and Trimingham Chalk and various other British "Mucronata-" and "Quadrata-chalk" localities, preserved in Sedgwick Museum, Cambridge; the Geological Survey and Museum, London; and in the private collection of Mr. C. W. Wright, London. The writer wishes to express his gratitude to Mr. A. G. Brighton,

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Mr. Richard V. Melville, and Mr. C. W. Wright, for making these collections available for this study. Palaeontological descriptions of the *Belemnitella*-like forms dealt with in this paper will be published elsewhere at some later date.

The writer has attempted to correlate the zones of the Norwich and Trimingham Chalk with the Campanian and Maestrichtian stages and with the continental palaeontological zones, instead of using for this purpose such vague and rather confusing terms as Lower, Middle, and Upper Senonian. The customary correlation of the younger British Upper Cretaceous formations and their palaeontological zones with the standard divisions of the Upper Cretaceous series solely by means of the latter terms is thought to be largely outdated by the modern progress of stratigraphical and palaeontological knowledge on the Upper Cretaceous.

A delimitation of Senonian, Campanian, and Maestrichtian stages in their West European type-areas is attempted first, because the widely divergent interpretations of these standard divisions have made them a matter of controversy among students of Cretaceous stratigraphy. The writer's attempt to compose these differences of opinion is based on principles recommended by Muller (1941, pp. 1427–9), Muller and Schenk (1943, pp. 267–9), and Arkell (1946, pp. 1–3), and discussed elsewhere (Jeletzky, 1949*b*, pp. 498–9).

2. Delimitation of the Senonian, Campanian, and Maestrichtian Stages

In modern literature there is a tendency to treat the Maestrichtian stage of Dumont (1849, pp. 360–1) as an independent stage of the Upper Cretaceous series (e.g. Spath, 1926 (corr. table opp. p. 80) ; Leriche, 1927, pp. 295–9 ; Withers, 1935, pp. 40–1 ; Muller and Schenk, pp. 271–3 ; Jeletzky, 1948*a*, p. 596 ; 1949*b*, pp. 499–500). At the same time, a great many students still consider the Maestrichtian as a substage of the Senonian of d'Orbigny (1842, 1852), equal in rank to Coniacian, Santonian, and Campanian (e.g. Haug, 1908–1911 ; pp. 1163–1171 ; Voigt, 1929, pp. 102–4 ; Bubnoff, 1935 ; Arkell, 1946, pp. 4–5 ; Abrard, 1948, pp. 10, 11, 13).

In the opinion of the writer Maestrichtian should be introduced as an independent stage between the Senonian and Danian simply because there are no known equivalents of the Maestrichtian, neither in the type area of the Senonian stage of d'Orbigny (1842, 1852), nor in the type locality of the Campanian stage of Coquand (1857*a–b*). The latest research of Abrard (1931, pp. 24–5 ; 1948, pp. 231, 233, 279–280) has, indeed, shown that at the type locality of the Campanian stage in south-west France, near Champagne, the beds with *Bostrychoceras*

polyplocum (Roemer), *Scaphites gibbus* Schluter, *Pachydiscus oldhami* (Sharpe), *Micraster brogniarti* Hebert, *Magas pumilus* Sowerby, *Crania ignabergensis* Retzius, etc. (horizons P3, Q), were originally included in Upper Campanian and not in lowermost Dordonian (an invalid synonym of Maestrichtian). These results of Abrard agree perfectly with the stratigraphic succession of the Upper Campanian and Lower Maestrichtian faunas established for Middle Poland by Pożariski (1938, pp. 18–24, 72–9), and for the southern part of the Donetz Basin and the Crimea by Mikhailov (1947, pp. 2021–3, 1948, p. 9). Yet these uppermost beds of the Campanian stage are at any rate not older than the uppermost beds of the Meudon Chalk and its equivalents in the Paris Basin (see Abrard, 1931, pp. 24–5 ; 1948, pp. 231, 233). It will be shown later in this paper that these latter may even be somewhat older than the uppermost Campanian beds with *B. polyplocum* (Roem.). Thus also the youngest beds of the Senonian stage of d'Orbigny (1842, pl. 236 *bis*, p. 320 ; 1852, pp. 666–691) in its type-area are apparently not younger than the *Bostrychoceras*-zone of the Campanian stage. Campanian becomes thus an upper substage of the Senonian stage.

Leriche (1927, pp. 295–9) and Abrard (1931, pp. 24–5) have shown that these uppermost beds of the Campanian and Senonian stages are equivalent only to the Nouvelles Chalk of Belgium. Already the Spiennes non-phosphatic chalk which directly overlies Nouvelles Chalk is undoubtedly younger than the highest beds either of the Campanian or the Senonian. The first appearance of the typical fauna of the Dordonian stage of south-western France, including *Pachydiscus gollevillensis* d'Orb., *P. colligatus* Binkh., *Schaphites constrictus* Sow., *Hemipneustes* spp., *Ostrea lunata* Nillss., in the Spiennes Chalk, makes this perfectly clear ; thus, Leriche (1927, pp. 295–9) places the lower boundary of the Maestrichtian at the base of the non-phosphatic Spiennes Chalk and correlates the latter with the Dordonian stage of Coquand (1857*a–b*).

This delimitation of the Maestrichtian, Senonian, and Campanian stages is in perfect agreement with the original scope of the Maestrichtian stage as proposed by Dumont (1849, pp. 260–1) ; yet as the original definition has been interpreted in a different sense by many later authors (e.g. Cornet and Briart, 1874, p. 545 ; Withers, 1935, pp. 40–41), it is necessary to review this problem as well.

Dumont's (1849, p. 361) original definition of the Maestrichtian stage is, indeed, very obscure ; he states only : " Le dernier système, dont le nom rappelle celui de la ville de Maestricht, ou il est depuis longtemps connu par les fossiles qu'il contient, commence, dans quelques localités de la province de Limbourg, par la glauconie sableuse ou du calcaire glauconifère ; il comprend le calcaire grossier

exploité aux carrières de Maestricht, celui de Folx-les-Caves et de Ciply, et correspond au calcaire pisolitique du bassin de Paris."

It is difficult to infer from this statement how much was assigned by Dumont to his "système Maestrichtien" below the "calcaire grossier de Maestricht" and its equivalents in Belgium. Yet as his "glauconie sableuse" and "calcaire glauconifère" cannot be anything but the Hervian Greensands, Gulpen Chalk, and Kunrade Limestone of the Netherlands, or phosphatic Chalk of Ciply and non-phosphatic Chalk of Spiennes, in Belgium, it is apparent that Leriche (1927, pp. 295–9) is right in contending that this original definition includes not only the Maestricht tuff and its equivalents, but older beds as well. Thus, it is entirely proper to include in the Maestrichtian stage all Upper Cretaceous beds in the type area of Dumont (1849, pp. 260–1) which are older than the Danian and younger than the Senonian of d'Orbigny (1842, 1852) and the Campanian of Coquand (1857*a–b*), as Leriche (1927) has already done.

Thus, in Belgium the lower boundary of the Maestrichtian should be drawn between the non-phosphatic Chalk of Spiennes and the Chalk of Nouvelles. This boundary, however, is not so clear in the Netherlands, where the stratigraphic relationships between the Kunrade Limestone, which is undoubtedly Lower Maestrichtian, the Gulpen Chalk, and the Hervian Greensands are still obscure. It appears probable that the last two are partly equivalent to the Kunrade Limestone and of Lower Maestrichtian age at least in part (see the correlation table). Indeed, the fauna of the Gulpen Chalk includes such Lower Maestrichtian index fossils as *B. lanceolata* (personal determination) and *Scaphites tridens* Kner (Umbgrove, 1925–6, pp. 263–273). Similarly *B. lanceolata* has been determined by the writer at the top of the Hervian Greensands (Emma II), together with *B. mucronata*, and *Diplomoceras* cf. *cylindraceus* (Defrance) and *P. colligatus* have been described from these beds by Weijden (1943). Accordingly, the boundary between the Campanian and the Maestrichtian in the Netherlands lies in all probability between the Gulpen Chalk and the uppermost Hervian Greensands.

These suggestions as to the stratigraphic relationship between the Hervian Greensands, Gulpen Chalk, and Kunrade Limestone, however, are opposed to the views of Umbgrove (1925–6, p. 277) and Voigt (1929, pp. 102–4), who accept these formations as persistent stratigraphic horizons superimposed on one another throughout the area. They ascribe the local disappearance of one or other of these formations to the differential faulting and tilting of the area with consequent local erosion. The palaeontological evidence tends to favour the opposite and older views of Grossouvre (1901, p. 323) and other authors, who

interpreted all these formations as largely contemporary facies. Our present knowledge of the stratigraphy and fauna of the Netherlands Maestrichtian is too fragmentary to admit of a final conclusion, and it may be that both views are partly correct. The above facts make the boundary between the Campanian and Maestrichtian stages, as suggested by Leriche (1927) and accepted in this paper, the only valid one, according to the principle of priority and type localities. It also coincides essentially with the first appearance of the cosmopolitan Maestrichtian fauna of ammonoids, including *Pachydiscus egertoni* (For.), *P. gollevillensis* d'Orb., *Hauericeras gardeni* Bayle, *Scaphites constrictus* Sowerby, *Diplomoceras cylindraceus* Defr., *Bostrychoceras schloenbachi* Favre, etc., and of the oldest Maestrichtian assemblage of the Eurasian boreal province, including *Scaphites tridens* Kner, *B. lanceolata* (Schloth.), *Trigonosemus pulchellum* Nils., *O. lunata* Nils., etc. At the same time the youngest Upper Campanian fauna, including *Pachydiscus oldhami* (Sharpe), *P. wittekindi* (Schlüt.), *P. portlocki* (Sharpe), *S. gibbus*, *S. spiniger* Schlüt., *Bostrychoceras polyplocum* (Roemer), *B. mucronata* mut. *minor* nov. mut., *B. langei* (Schatsky in coll.), *B.* nov. sp. aff. *mucronata* (Schloth.), *Micraster brogniarti* Hebert, etc., does not persist into the oldest Maestrichtian except for a few rare occurrences in solitary specimens. Pożarisky (1938, pp. 31, 74), however, has discovered transition beds with a mixed fauna between the Campanian and Maestrichtian stages in Middle Poland.

These facts also indicate that the common practice of downward extention of the Maestrichtian stage introduced by Haug (1908–1911, pp. 1302 and *seq.*) and more or less closely followed by Spath (1926), Gignoux (1943), Muller and Schenk (1943), Mikhailov (1947, pp. 2021–3 ; 1948, p. 9), and many other authors is invalid and should be abandoned. The restriction of the Maestrichtian stage to the Maestricht tuff and its equivalents, as proposed by Cornet and Briart (1874, p. 545) and followed by Umbgrove (1925–6), Withers (1935), Bubnoff (1935), and other authors is likewise invalid. Even less satisfactory is the suggestion of Kühn and Zinke (1939, pp. 341–3) to restrict the Maestrichtian stage to the Maestricht tuff, while introducing for the beds with *P. egertoni* For., *P. colligatus*, and *P. wittekindi* the vague and purely local name Aturian. This proposal not only ignores the original concepts of both terms Maestrichtian and Aturian, but unites the palaeontological zones of *P. egertoni* and *P. wittekindi*, which should be assigned to the Lower Maestrichtian and Upper Campanian respectively. The concept of Maestrichtian held by Voigt (1929, p. 102) agrees more closely with one here proposed ; but the writer objects to his interpretation of the Maestrichtian as primarily a Mediterranian facies of the boreal " upper Mucronata Chalk ".

3. Trimingham and Norwich Chalk, their Belemnoid Fauna, Stratigraphy, and Zonal Names

Jukes-Browne (1904, pp. 249–251) appears to be the first to recognize clearly the superposition of the Trimingham Chalk on the Norwich Chalk with *B. mucronata* (Schloth.) and *B. polyplocum* (Roem.). Ever since there has been and is still a general agreement among British geologists that the former is the youngest Upper Chalk formation yet known in this country and that there are no known Upper Chalk localities in Great Britain contemporary with it.

A new zone of *Ostrea lunata* was proposed by Jukes-Browne (1904, pp. 261–270) for the Trimingham Chalk, while restricting the zone of *B. mucronata* to the Norwich Chalk and its equivalents elsewhere in Great Britain. This new zonal name has caused an animated discussion between Brydone (1906*a*, 1906*b*, 1908) and Jukes-Browne (1906) himself. Having abandoned his former views as to the contemporaneity of the Norwich and Trimingham Chalk (Brydone, 1900, p. 1), Brydone proposed to replace the "*lunata*-zone" by "*Terebratulina gracilis*-zone", arguing that *O. lunata* does not occur in more than half the beds making up the Trimingham Chalk. This objection notwithstanding, the name "*lunata*-zone" has been accepted by many British geologists. However, Spencer (1914, pp. 104, 143–6), Withers (1935, pp. 60–1), and a few other authors, do not use it and include "*lunata*-zone" with "*mucronata*-zone" as "upper *mucronata*-beds".

The study of the belemnoid fauna of the Trimingham Chalk by the writer has shown that, as already suspected by the late Dr. Blackmore (see Brydone, 1938, p. 9), the "*B. mucronata*" commonly listed from it actually belongs to another belemnitella-like form in nearly all cases. So of 646 guards studied by the writer from the Trimingham Chalk, and representing all the beds distinguished there by Brydone (1900, 1906*a*, 1908, 1938), no less than 630 could be determined as *Belemnella lanceolata* (Schloth.) or its variants and mutations. These represent nearly all growth stages of this species and easily find their places within the range of its infraspecific variation known to the writer from any complete section of "Lanceolata Beds" on the Continent. No local variants have so far been discovered in the Trimingham Chalk and here, as elsewhere, *B. lanceolata* exhibits considerable plasticity in all external characters (see Jeletzky, 1949*a*, p. 264), being at the same time very stable in its diagnostic features. Neither primitive *Belemnella* ancestral to *B. lanceolata* (see Jeletzky, 1949*a*) nor any forms transitional between them and the latter form were observed in Trimingham. *Belemnella lanceolata* mut. *sumensis* Jeletzky, 1949*a*, characteristic of the uppermost Lanceolata Beds, is common here, together with few guards probably referable to *B. lanceolata* (Schloth.) mut. *junior* Nowak 1913.

Only twelve of the 646 guards studied by the writer from the Trimingham Chalk belonged to *Belemnitella* ex gr. *mucronata* (Schloth.). One of these appears to agree with "*Belemnites lanceolatus*" Sharpe *non* Schlotheim from the Norwich Chalk. Three others belong to a particularly slender variant of *B. mucronata* (Schloth.) (= *B. mucronata* (Schloth.) mut. *minor* nov. mut.),[1] and the rest represents either *B. langei* (Schatsky in coll.) or intermediate forms between it and *B. mucronata* mut. *minor* nov. mut. already referred to. From these twelve specimens of *B.* ex gr. *mucronata* (Schloth.) six are from the lowermost *Porosphaera* Beds, five are labelled General Beds, and one is without any exact horizon. It thus appears that *B.* ex gr. *mucronata* is extremely rare in all beds of the Trimingham Chalk. *B. lanceolata*

[1] In previous papers the writer (Jeletzky, 1948*a*, p. 346 ; 1948*b*, pp. 568–589, Beil. 1) has reserved the name *Belemnitella mucronata* (Schloth.) mut *junior*, of Nowak (1913, 1917), for this slender minor form of *B. mucronata* from middle and upper beds of Upper Campanian (= *Mucronata* Beds s. str.) Simultaneously all belemnitella-like forms from the Upper Maestrichtian (above Lanceolata Beds) have been referred indiscriminately to *B.* ? *americana* (Mort.) Arkh. Since then, however, the study of original belemnoid material from Maestricht Tuff and its equivalents has shown that the belemnitella-like forms from this formation and its equivalents in Germany (Hemmoor) and Poland (Zaszków) are distinct from *B.* ? *americana* (Mort.) em. Arkh., and from the slender minor form of *B. mucronata*, above referred to, as well. Since the belemnoids from Maestricht Tuff and its equivalents in north-west Europe are identical with one of the forms figured by Nowak (1913, pl. 42, fig. 18) as *B. mucronata* (Schloth.) mut. *junior*, and Nowak (1913, p. 398) himself insisted on the identity of his mutation with the belemnoid from the Maestricht Tuff, this name is specifically valid for this form and not for any other erroneously included with it by him. Our action in this matter is thus invalid and our slender minor form must be renamed. The writer designates it as *Belemnitella mucronata* (Schloth.) mut. *minor* nov. mut., with the specimen figures by Sharpe, 1853–7, pl. 1, fig. 2 *a–c*, as holotype. *B. mucronata* (Schloth.) mut. *junior* Nowak, as above restricted, represents an independent species which should be referred to as *Belemnitella junior* Nowak, 1913, s. str. It has also been established that "*Belemnitella americana*" Arkhangelsky 1912 *non* Morton 1829, above referred to as *B.* ? *americana* (Mort.) *em.* Arkh. is specifically and generically distinct from the true *Belemnitella americana* (Morton). Thus, it has to be renamed, too. The name *Belemnella casimirovensis* (Skolozdrówna, 1932, in coll.) is available for this form (cf. Jeletzky, 1948*b*, pp. 587, footnote), and should therefore be used for "*Belemnitella americana*" Arkhangelsky, 1912 *non* Morton 1829. The above conclusion affects the stratigraphical subdivision of the Upper Maestrichtian previously suggested by the writer. It now appears that the Upper Maestrichtian has two belemnoid zones : the upper zone carries *Belemnella casimirovensis* (Skolozdr. in coll.), while a lower one with *Belemnitella junior* Nowak s. str. lies between the former and the Lanceolata Beds (= Lower Maestrichtian). Since the Maestricht Tuff and its equivalents in north-west Europe and Poland carry *B. junior* Nowak s. str. they can hardly be correlated with the "*Americana* Beds" (= Zone of *B. casimirovensis*) of Poland and Russia (Jeletzky, 1948*b*), or with the Stevensian substage of Denmark (Brotzen, 1945, p. 59), which seems to be equivalent to the former (see the correlation chart attached to this paper). However, it is not yet known whether the above-mentioned belemnoids are restricted to their respective zones or whether they may occur together in some beds.

mut. *sumensis* appears to predominate in the General Beds of the Trimingham Chalk, while *B. lanceolata* var. *inflata*, var. *gracilis* and var. *typica* characterize the *Porosphaera* and Sponge Beds. This is in complete agreement with their distribution in the rest of boreal province of Eurasia (see Jeletzky, 1949*a*, pp 268–274), and supports the conclusions of Brydone (1908, 1938) as to the relative age of these beds.

The writer knows *B. lanceolata* in England from the Trimingham Chalk only ; all other British Upper Chalk localities contain exclusively other *Belemnitella*-like forms belonging to the genus *Belemnitella* d'Orbigny 1842 em. Jeletzky 1941. Neither the Norwich nor the Antrim Chalk has yielded a single guard of *B. lanceolata* or any other *Belemnella* species, to judge by the material available for study. It is apparent that the author's suggestion (Jeletsky, 1948*a*, p. 345, footnote) of the possible occurrence of *B. lanceolata* in the Dorset Chalk and Isle of Wight Chalk cannot be maintained. The forms from these localities, referred to as *B. lanceolata* by Jukes-Browne (1904, p. 12), Crick (1910, p. 353, footnote), and other authors are, to judge from available material, nothing else than Belemnitellids, similar to *B. lanceolata* only in the general form of the guard (see Jeletzky, 1948*b*, pp. 597–9, Abb. 1*a–b*, 2). In Great Britain, as elsewhere in Northern Eurasia, true *B. lanceolata* is restricted to Lower Maestrichtian (Lanceolata Beds), as employed by the writer (see correlation chart).

This revision of *Belemnitella*-like forms from the British Upper Chalk necessitates few changes in zonal nomenclature. In the absence of any better zonal fossils, the name " *lunata* zone " could be considered adequate to designate the faunal assemblage of the Trimingham Chalk, despite the fact that the fossil itself occurs there only sporadically (Jukes-Browne, 1906, pp. 93–4). Now that it has been shown that the true *B. lanceolata* is restricted to Trimingham Chalk, while true *B. mucronata* is almost exclusively confined to the underlying " *mucronata* " zone s. str., the former species appears to be far more appropriate as an index fossil for the Trimingham Chalk. Indeed, *B. lanceolata* seems to be fairly common in all its beds from top to bottom, while *O. lunata*, as Brydone (1906*a*, pp. 14–15) points out, is totally absent in more than half of these beds. It is convenient also that *B. lanceolata* is easy to determine, even from fragments of the guard, and that this form represents about the best regional index fossil of Lower Maestrichtian throughout the boreal province of northern Eurasia. Thus, *B. lanceolata* not only fulfils all the requirements of " provincial zone " fossil, as defined by Brydone (1906*b*, pp. 285–6) far better than *O. lunata*, but simultaneously serves as a perfect " international zone " fossil. Its use would eliminate the ambiguity caused by the common but illfounded belief that *B. mucronata*

abounds in Trimingham Chalk, while "*B. lanceolata*" also occurs in "*mucronata* zone" and even in the underlying zones of *G. quadrata* and *O. pilula*. In its new definition, "*mucronata* zone" would be restricted to the beds older than Trimingham Chalk designated by Spencer (1914, pp. 143–6) as "middle" and "lower" *mucronata* beds, thus agreeing with the Mucronata Beds of eastern and north-western Europe, as restricted by the writer (Jeletzky, 1948*b*, pp. 584, footnote, 586).

The belemnoid fauna of the *mucronata* zone, as above restricted, admits subdivision into two palaeontological sub-zones, as the sturdy and strongly ornamented guards of *B. mucronata* (Schloth.) mut. *senior* Nowak are nearly restricted to its lower horizons in Norfolk and elsewhere in Great Britain. On the contrary, the upper horizons of the *mucronata* zone, in Norfolk, carry the above-mentioned *B. mucronata* (Schloth.) mut. *minor* nov. mut., "*B. lanceolatus*" Sharpe *non* Schloth., and *B. langei* (Schatsky in coll.) all of which forms are absent in the "lower" *mucronata* beds with *B. mucronata* mut. *senior*. This younger belemnoid fauna appears also at Antrim. Both at Norfolk and at Antrim it appears to be associated with the ammonoid fauna of the *B. polyplocum*-zone, whereas no ammonoids are known from the "lower" *mucronata* beds with *B. mucronata* mut. *senior*, with the possible exception of *Baculites anceps* Lam.

It is doubtful whether these "lower" and "upper" *mucronata* beds agree respectively with the "lower" and "middle" *mucronata* beds of Spencer (1914, pp. 145–6) and other authors.

4. Correlation of the Norwich and Trimingham Chalk with the Campanian and Maestrichtian Stages

The age of the Trimingham and Norwich Chalk in terms of the international divisions of the Upper Cretaceous series still remains controversial both in British and in west European literature. This is primarily due to a misinterpretation of the Maestrichtian stage. If we apply the concept of the Maestrichtian and Campanian stages adhered to in this paper to the Norwich-Trimingham succession, it becomes apparent at once that in accordance with the suggestion of Leriche (1927, p. 297, footnote), the boundary between these stages in Norfolk must be placed at the base of Trimingham Chalk, leaving the chalk of Norwich in the Upper Campanian.

The cephalopod fauna of the upper beds of the Norwich and Antrim Chalk, as now known, lucludes *P. oldhami*, *P. portlocki*, *B. polyplocum*, *D.* aff. *cylindraceus*, *Phylloceras pergensi* (Schlüter), *B. mucronata* mut. *minor*, *B. langei* Schatsky, and "*B. lanceolatus*" Sharpe *non* Schloth.; *B. lanceolata* is apparently absent. Older beds of Norwich carry *B. mucronata* (Schloth.) mut. *senior* Nowak.

The Trimingham Chalk lacks nearly all these species, while containing a totally different faunal assemblage, including *B. lanceolata* (about 98 per cent of belemnoids), *B.* ex gr. *mucronata* (about 2 per cent of total), *Ostrea lunata* Nilsson, *Trigonosemus pulchellum* Nilsson, *T. elegans* d'Orbigny, *Thecidea vermicularis* (Schlotheim), and *Pecten pulchellus* Nilsson.

It is clear that the faunal assemblage of the Norwich and Antrim Chalk is Upper Campanian in its affinities. That of Trimingham Chalk is, on the contrary, typically Maestrichtian, despite the lack of index ammonoids. The two have practically nothing in common except *Baculites faujasi* Lamarck and *B.* ex gr. *mucronata*, and the latter, moreover, is extremely rare in Trimingham Chalk. While undoubtedly Upper Campanian in age, the Norwich and Antrim Chalk might possibly include beds somewhat younger than the youngest beds of the Nouvelles and Meudon Chalk, which show neither *B. polyplocum* nor typical *B. mucronata* (Schloth.) mut. *minor*, characteristic of the " upper " *mucronata* beds at Norwich and Antrim, of the uppermost Campanian near Champagne, and of the " upper " *mucronata* beds at Haldem, in Westfalen. At the same time, the fauna of the Nouvelles, Meudon, and d'Epernay Chalk, shows more affinities with that of the older horizons of the Norwich Chalk, and of the " *mucronata* " beds of Dorset, Hampshire, and the Isle of Wight, where ammonoids are practically absent and belemnoids are represented mainly by *B. mucronata* (Schloth.) mut. *senior* Nowak. All these beds are probably equivalent to the zone of *Hoplitoplacenticeras vari* (Schlüt.).

The above faunal assemblage of the Trimingham Chalk not only establishes its Maestrichtian age in general but also suggests definitely its contemporaneity with the " assise de Spiennes " and with the Maestrichtian part of the Rugen succession as proposed by Brydone (1900, p. 7), Spencer (1914, p. 145), Umbgrove (1925–6), Leriche (1927), and Withers (1935). Its total or even partial correlation with the Maestricht Tuff, as proposed by Jukes-Browne (1904, pp. 249–251), Bubnoff (1935, p. 972, chart xi), and by Brydone (1938, p. 16) lacks any palaeontological evidence, as *B. lanceolata* goes up to the top of the Trimingham succession, and *B. junior* s. str. is absent even in the highest beds. In Belgium and the Netherlands *B. lanceolata* characterizes the Spiennes Chalk, the phosphatic Chalk of Ciply, the limestone of Kunrade, and occurs also in Gulpen Chalk. In the overlying Saint-Symphorien Tuff, Maestricht Tuff, and their equivalents (see correlation chart), *B. lanceolata* is rare, if not absent altogether, while *B. junior* s. str. is dominant. Also *O. lunata* and *T. pulchellum* are, despite the views of Bubnoff (1935, pp. 967–8, chart xi) and other German authors, and Brydone (1938, pp. 7–8), not restricted to the Upper Maestrichtian (=Maestricht Tuff, etc.). Indeed, they are mostly associated with

B. lanceolata and other index fossils of the Lower Maestrichtian throughout the boreal province of Eurasia (see Leriche, 1927, p. 298 ; Schatsky, 1924, pp. 105–114, 126 ; Troelsen, 1937, pp. 261–2 ; Jeletzky, 1948*b*, pp. 589, 591, and others).

The predominance of *B. lanceolata* mut. *sumensis* in the upper beds (General Beds) of the Trimingham Chalk suggests definitely that the Lanceolata Beds (= Lower Maestrichtian) are here more or less fully developed. It is not yet clear whether the Upper Maestrichtian in Norfolk is absent because of non-deposition or erosion.

REFERENCES

ABRARD, R., 1931. Révision de la feulle de Provins au 80·000 m. *Bull. Serv. Carte Géol. France* (34), No. 179, 24–5.

—— 1948. *Géologie de la France*. Paris.

ARKELL, W. J., 1946. Standard of the European Jurassic. *Bull. Geol. Soc. America*, 57, 1–34.

ARKHANGELSKY, A. D., 1912. Verkhne-melovye otlozheniya wostoka Evropeiskoi Rossii (The Upper Cretaceous deposits of the Eastern part of European Russia). *Materialy dlya geologii Rossii*, 25 St. Petersburg (Russian).

BROTZEN, F., 1945. De geologiska resultaten från borrningarna vid Hollviken. Preliminar rapport. Del I : Kritan. *Sveriges Geologiska Undersökning Årsbok* 38, Ser. C, No. 465 (Swedish with English summary).

BRYDONE, R. M., 1900. *Stratigraphy and fauna of Trimingham Chalk*. London.

—— 1906*a*. Further notes on the stratigraphy and fauna of the Trimingham Chalk. *Geol. Mag.*, 53, 13–22, 72–8, 124–131.

—— 1906*b*. The Trimingham Chalk as a zone. *Geol. Mag.*, 53, 285–6.

—— 1908. On the subdivisions of the Chalk of Trimingham (Norfolk). *Quart. Journ. Geol. Soc.*, 64, 401–412.

—— 1938. *On Correlation of Some of the Norfolk Exposures of Chalk with* Belemnitella mucronata. London.

BUBNOFF, S., 1935. *Geologie von Europa*. Bd. 2. Das ausseralpine Westeuropa T.2, Die Entwicklung des Oberbaues. Berlin.

COQUAND, H., 1857*a*. Notice sur la formation crétacé de la Charente. *Bull. Soc. Géol. France* (2), 14, 55–98.

—— 1857*b*. Position des *Ostrea columba* et *biauriculata* dans le groupe de la craié inférieure. *Bull. Soc. Géol. France* (2), 14, 745–766.

CORNET, L., and BRIART, A., 1874. Aperçu sur la géologie des énvirons de Mons. *Bull. Soc. Géol. France* (3), 2, 534–553.

CRICK, G. C., 1910. On *Belemnocamax Boweri* n. gen. n. sp. a new Cephalopod from the lower chalk of Lincolnshire. *Proc. Geol. Assoc.*, 21, 360–5.

DUMONT, A., 1849. Rapport sur la carte géologique du Royame. *Bull. Acad. Roy. Belgique*, 16, 351–373.

EVANS, J. W., and STUBBLEFIELD, C. J., 1929. *Handbook of the Geology of Great Britain*. London.

GIGNOUX, M., 1943. *La géologie stratigraphique*. 3me ed., Paris.

GROSSOUVRE, A. DE., 1901. Récherches sur la craie supérieure. I. Stratigraphie générale. Avec une monographie du genre *Micraster* par J. Lambert. *Mémoires pour servir à l'explication de la carte géologique de la France*. Fasc. 1–2, Paris.

HAUG, E., 1908–1911. *Traite de géologie*. Paris.

JELETZKY, J. A., 1948*a*. Sowerby's and Sharpe's *Belemnites lanceolatus* and their relation to *Belemnites lanceolatus* Schlotheim, 1813. *Geol. Mag.*, 85, 338–348.

—— 1948*b*. Zur Kenntnis der Oberkreide der Dnjepr-Donetz Senke . . . *Geol. Fören. Förh.*, 70, 583–602.

JELETZKY, J. A., 1949*a*. Uber die taxonomische Bedeutung einiger morphologischen Elemente des Rostrums bei belemnitellengartigen Formen . . . *Neues Jahrb. Min., Monatshefte*, Ser. B, 257–287.

—— 1949*b*. Upper Cretaceous stratigraphy. *Geol. Fören. Förh.*, 71, 497–500.

JUKES-BROWNE, A. J., 1904. The Cretaceous rocks of Gt. Britain. III. Upper Chalk. *Mem. Geol. Survey*.

—— 1906. The zone of *Ostrea lunata*. *Geol. Mag.*, 53, 93–4, 335–6.

KUHN, O., and ZINKE, G., 1939. Die helvetische Kreide von Mattsee. *Neues Jahr. Min.*, etc., *Beil.* Bd. 81, 327–346.

LERICHE, M., 1927. Les poissons du crétacé marin de la Belgique et du Limburg hollandais ; les résultats stratigraphiques de leur étude. *Bull. Soc. Belge de Géol.*, 37, 199–299.

MIKHAILOV, N. P., 1947. O granitze mezhdu kampanskim i maastrichtskim yarusami (The boundary between Campanian and Maestrichtian stages). *Doklady Akad. Nauk. U.S.S.R.*, 58, 2021–3 (Russian).

—— 1948. Zonalnoie delenie verkhnei chasti melovykh otlozhenii Kryma i Zapadnoi Ukrainy po golovonogim (The zonal subdivision of the upper part of the Cretaceous deposits of Crimea and Western Ukraine according to Cephalopods). *Bull. Soc. Nat. Moscou, N.S., Otd. Geol.*, 23, 2–10 (Russian).

MULLER, S. W., 1941. Standard of the Jurassic system. *Bull. Geol. Soc. America*, 52, 1427–1444.

—— and SCHENCK, H. G., 1943. Standard of the Cretaceous system. *Bull. Amer. Assoc. Petrol. Geologists*, 27, 262–278.

NOWAK, J., 1913. Untersuchungen uber die Cephalopoden der oberen Kreide in Polen. 3. *Bull. Acad. Sci. Cracovie*, Ser. B, 336–412.

—— 1917. Die Verbreitung der Cephalopoden im polnischen Senon. *Bull. Acad. Sci. Cracovie*, Ser. A, 129–152.

D'ORBIGNY, A., 1842. *Paléontologie française. Terrains crétacées*, t. 2. Paris.

—— 1852. *Cours elémentaire de paléontologie et de géologie stratigraphiques*. Paris.

POŻARISKI, W., 1938. Senonsstratigraphie im Durchbruch der Weichsel zwischen Rachow und Puławy in Mittelpolen. *Bull. Inst. Geol. Pologne*, No. 6 (Polish with German summary).

SCHATSKY, N. S., 1924. La stratigraphie et la téctonique du Crétacé supérieur et du Paléogene dans l'extremites septentrionale de la chaine du Donetz. *Trudy Osoboy Komissii Kurskich Magnitnych Anomalii. Geol. Otdel*, v, 82–152 (Russian, with French summary).

SHARPE, D., 1853–7. Chalk Cephalopoda. *Mon. Palaeont. Soc.* London.

SPATH, L. F., 1926. On new ammonites from the English Chalk. *Geol. Mag.*, 63, 77–83.

SPENCER, W. K., 1914. The Evolution of the Cretaceous Asteroidea. *Phil. Trans. Roy. Soc.*, 204, B.

TROELSEN, J., 1937. Om den stratigraphiske Indeling af Skrivekridtet i Danmark. *Medd. Dansk Geol. Foren.*, 9, 260–3 (Danish).

UMBGROVE, J. H. F., 1925–6. Bijdrage tot de Kennis der Stratigraphie, Tektoniek en Petrographie van het Senoon in Zuid-Limburg. *Leidische Geol. Mededeel.*, 1, 255–332 (Dutch).

VOIGT, E., 1929. Die Lithogenese der Flach und Tiefwassersedimente des jüngeren Oberkreidemeeres . . . *Jahrb. Halleschen Verbandes zur Erforschung Mitteldeutscher Bodenschätze*, 8, N.F.

WEIJDEN, W. J. M. VAN DEN, 1943. Die Macrofauna der Hervenischen Kreide mit besonderer Berücksichtigung der Lamellibranchiaten. *Mededeelingen Geol. Stichting*, Ser. C–IV–2, No. 1.

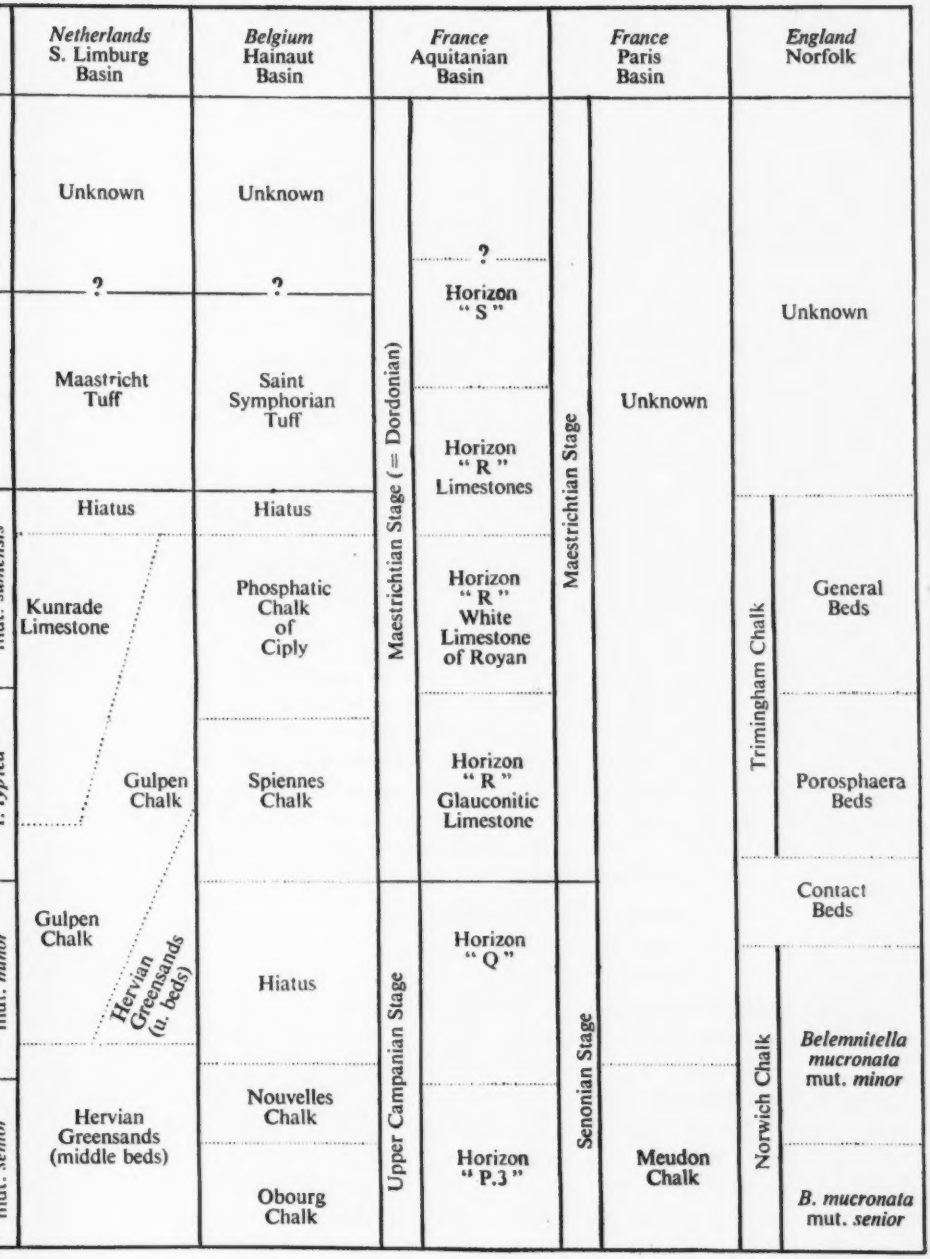
WILLIAMS-MITCHELL, E., 1948. The zonal value of Foraminifera in the Chalk of England. *Proc. Geol. Assoc.*, 59, 91–112.

WITHERS, T. H., 1935. Catalogue of Fossil Cirripedia. 2, Cretaceous. *British Museum (Natural History)*.

SENONIAN STAGE		MAESTRICHTIAN STAGE			Zones of the Campanian and Maestrichti
CAMPANIAN SUBSTAGE		LOWER MAESTRICHTIAN SUBSTAGE	UPPER MAESTRICHTIAN SUBSTAGE		
U. Campanian (Mucronata Beds)		Lanceolata Beds			
Zone of *H. vari*	Zone of *B. polyplocum*	Zone of *P. egertoni* and *B. lanceolata* (s.l.)			

JELETZKY, J. A., 1949*a*. Uber die taxo
morphologischen Elemente des Rostr
Formen . . . *Neues Jahrb. Min., Mo*
—— 1949*b*. Upper Cretaceous stratigraphy. C
JUKES-BROWNE, A. J., 1904. The Cretaceou
Upper Chalk. *Mem. Geol. Survey.*
—— 1906. The zone of *Ostrea lunata*. *Geol. M*
KUHN, O., and ZINKE, G., 1939. Die helvetisch
Jahr. Min., etc., *Beil.* Bd. 81, 327–34
LERICHE, M., 1927. Les poissons du crétacé
Limburg hollandais ; les résultats st
Bull. Soc. Belge de Géol., 37, 199–299.
MIKHAILOV, N. P., 1947. O granitze mezhdu
yarusami (The boundary between C
stages). *Doklady Akad. Nauk. U.S.S.*
—— 1948. Zonalnoie delenie verkhnei chasti
i Zapadnoi Ukrainy po golovonogim
upper part of the Cretaceous depo
Ukraine according to Cephalopods).
Otd. Geol., 23, 2–10 (Russian).
MULLER, S. W., 1941. Standard of the Jura
America, 52, 1427–1444.
—— and SCHENCK, H. G., 1943. Standard of
Amer. Assoc. Petrol. Geologists, 27, 2
NOWAK, J., 1913. Untersuchungen uber di
Kreide in Polen. 3. *Bull. Acad. Sci. C*
—— 1917. Die Verbreitung der Cephalopode
Acad. Sci. Cracovie, Ser. A, 129–152.
D'ORBIGNY, A., 1842. *Paléontologie française.*
—— 1852. *Cours elémentaire de paléontologie*
Paris.
POŻARISKI, W., 1938. Senonsstratigraphie i
zwischen Rachow und Puławy in M
Pologne, No. 6 (Polish with German s
SCHATSKY, N. S., 1924. La stratigraphie et la té
et du Paléogene dans l'extremites se
Donetz. *Trudy Osoboy Komissii Ku*
Geol. Otdel, v, 82–152 (Russian, with
SHARPE, D., 1853–7. Chalk Cephalopoda. *M*
SPATH, L. F., 1926. On new ammonites from th
63, 77–83.
SPENCER, W. K., 1914. The Evolution of the
Trans. Roy. Soc., 204, B.
TROELSEN, J., 1937. Om den stratigraphiske
Danmark. *Medd. Dansk Geol. Foren.*
UMBGROVE, J. H. F., 1925–6. Bijdrage tot
Tektoniek en Petrographie van het
Leidische Geol. Mededeel., 1, 255–332
VOIGT, E., 1929. Die Lithogenese der Flach
jüngeren Oberkreidemeeres . . . *Jahrb*
Erforschung Mitteldeutscher Bodensch
WEIJDEN, W. J. M. VAN DEN, 1943. Die M
Kreide mit besonderer Berücksichtig
Mededeelingen Geol. Stichting, Ser. C-
WILLIAMS-MITCHELL, E., 1948. The zonal value
of England. *Proc. Geol. Assoc.*, 59, 91
WITHERS, T. H., 1935. Catalogue of Fossil
British Museum (*Natural History*).

Zones of the Campanian and Maestrichtian						
MAESTRICHTIAN STAGE						
SENONIAN STAGE	CAMPANIAN SUBSTAGE	LOWER MAESTRICHTIAN SUBSTAGE	UPPER MAESTRICHTIAN SUBSTAGE			
U. Campanian (Mucronata Beds)		Lanceolata Beds				
Zone of *H. vari*	Zone of *B. polyplocum*	Zone of *P. egertoni* and *B. lanceolata* (s.l.)		*B. junior*	*B. casimirovensis*	
B. mucronata mut. *senior*	*B. mucronata* mut. *minor*	*B. lanceolata* f. *typica*	*B. lanceolata* mut. *sumensis*			



[To face page 208

The Rhombinidae, a New Family of Carboniferous Ostracoda

By P. C. Sylvester-Bradley

(PLATE XI)

Abstract

The Carboniferous ostracod *Rhombina* Jones and Kirkby is shown to have been misinterpreted. The genus is redescribed, a new family is erected for its reception, and a new genus, *Palaeophilomedes*, proposed as a second member of this family.

Jones and Kirkby (1874) described the genus *Rhombina* as a member of the " Cypridinadae ", on the basis of two specimens from the Carboniferous Limestone. They placed each in a different species : one (from Little Island, Cork) was named *R. hibernica* ; the other (from Visé, Belgium), *R. belgica*. The anomalous shape of this genus, as described by Jones and Kirkby, has long been a puzzle to students of Palaeozoic ostracoda : " Carapace-valve almost a rhomb in outline, obliquely truncate at both extremities, with nearly parallel lines, but more acutely (60°) at the anterior end than at the other (70°)."

The two specimens are preserved in the British Museum. It will be shown that both the specimens described were broken, incomplete, and misinterpreted. They are of the same genus and probably represent the same species as that described by these authors under the name *Cypridina oblonga*, of which one almost perfect specimen exists. The genus *Rhombina* is accordingly emended on the basis of the following redescription. A new family of the Myodocopa is erected to include *Rhombina*, and another genus created for the species described by Jones and Kirkby as *Philomedes bairdiana*. All but one of the nine specimens of the family at present known were collected by Joseph Wright from the Carboniferous Limestone of Little Island, Cork, Eire. The one exception is the specimen from Visé.

Order OSTRACODA Latreille

Suborder Myodocopa Sars

Family *RHOMBINIDAE* nov.

Diagnosis.—Myodocopa, with a down-curved, truncated rostrum, receding antero-ventral border, and a more or less well-marked ventral rim. Known forms rather large (4–8 mm.). Carboniferous.

Remarks.—Several specimens were referred by Jones and Kirkby to species of the genus *Bradycinetus*. This " genus ", as has now for long been known, is the female of *Philomedes*. It is probable that all Palaeozoic specimens referred to *Bradycinetus*, and also those referred to *Cypridina*, should more correctly be assigned to new genera, most of which would belong to families other than Rhombinidae.

Genus RHOMBINA Jones and Kirkby 1874

Type-species (here designated) : *R. belgica* Jones and Kirkby.

Diagnosis.—Rhombinidae, with a tumid posterior and no nuchal furrow. Posterior margin evenly curved.

RHOMBINA OBLONGA (Jones and Kirkby 1874)

Pl. XI, Figs. 1–4, and Text-figs. 1 and 2*a*

Cypridina oblonga Jones and Kirkby, 1874, p. 20, pl. v, fig. 12 *a–c*; and Jones, Kirkby, and Brady, 1884, p. 90.

? *Rhombina hibernica* Jones and Kirkby, 1874, p. 44, pl. ii, fig. 32 *a–c*; pl. v, fig. 13 *a–c*.

? *Rhombina belgica* Jones and Kirkby, 1874, pp. 44, 45, pl. v, fig. 14 *a–d*.

FIG. 1.

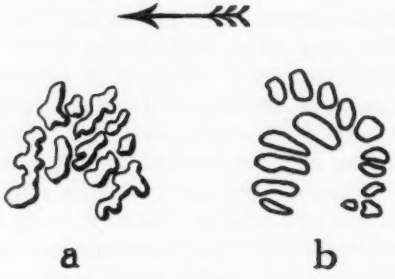


FIG. 2.

TEXT-FIG. 1.—*Rhombina oblonga* (Jones and Kirkby). Dorsal view of left valve, B.M. No. I. 6269, × 5·4 (actual length, 7·2 mm.).

TEXT-FIG. 2.—Muscle scar patterns of (*a*) *Rhombina oblonga* (Jones and Kirkby), Carboniferous; (*b*) *Philomedes brenda* (Baird), Recent. The arrow points towards the anterior.

Diagnosis and Description.—Rostrum large, down-curved. Dorsal margin curved. Antero-ventral margin receding. Posterior tumid, with a large, ill-defined, oval protuberance, sloping steeply to posterior margin (Text-fig. 1). A slight furrow parallel to the ventral margin delineates a marginal rim. Surface covered with faint papillae. Muscle-scar pattern (Text-fig. 2*a*) consisting of an approximately triangular group of irregular, elongated scars, presenting certain points of resemblance to the muscle-scar patterns of recent Myodocopa (Text-fig. 2*b* illustrates that of *Philomedes brenda*, for comparison). Length : 6 to 7½ mm.

This description is based on the following four specimens, all from the T. R. Jones' collection, now at the British Museum :—

I. 6269.—Carboniferous Limestone, Little Island, Cork. An almost perfect left valve. Pl. X, Fig. 1, Text-fig. 1 and 2*a*. Presumably this is the specimen referred to by Jones, Kirkby, and Brady, 1884, p. 90.

I. 6267.—Holotype. Carboniferous Limestone, Little Island, Cork. Imperfect right valve (rostrum missing). Pl. XI, Fig. 4. Figured upside down by Jones and Kirkby, 1874 (pl. v, fig. 12*a*), and interpreted by them as a left valve. The so-called beak of their figure is an irregular crack.

I. 6249.—Holotype of *R. hibernica*. Carboniferous Limestone, Little Island, Cork. An imperfect left valve. Pl. XI, Fig. 3. Figured by Jones and Kirkby first upside down (pl. ii, fig. 32*a*), and then right way up (pl. v, fig. 13*a*). The dorsal border is entirely missing, the margin figured by Jones and Kirkby being the deep score of a needle, presumably made when working the specimen out. The rostrum is also missing. The ventral marginal rim is well-marked.

I. 6247.—Holotype of *R. belgica*. Upper Carboniferous Limestone, Visé, Belgium. Specimen originally presented to Jones by Bosquet. An imperfect left valve (the rostrum missing). Pl. XI, Fig. 2 (Jones and Kirkby, 1874, pl. v, figs. 14*a–d*).

These four specimens, the only representatives of the genus known to me, provide insufficient evidence to prove the distinction of the three species recognized by Jones and Kirkby. Certain differences in outline are observable, as can be readily seen from a study of Pl. XI. Until further material becomes available it is proposed to regard all three names as synonymous. "*Cypridina oblonga*" has priority by page precedence as, it would appear, will be demanded by the new Rules of Nomenclature.

Genus Palaeophilomedes nov.

Type-species : *Philomedes bairdiana* Jones and Kirkby, 1874.

Diagnosis.—Rhombinidae, with a short nuchal furrow, directed towards the posterior. Posterior margin triangular. The available material is not well enough preserved to determine whether or no a siphon is developed at the apex of this triangle.

Palaeophilomedes bairdiana (Jones and Kirkby)

Philomedes bairdiana Jones and Kirkby, 1874, p. 43, pl. ii, figs. 30, 31 *a–c*.
Pl. XI, Figs. 5–8

Diagnosis and Description.—Dorsal border straight, ventral border curved. A shallow furrow runs parallel to the ventral border delineating a marginal rim. Posterior produced to a blunt angle. A shallow, sinuous nuchal furrow, in length between a third and a half the height of the shell, is developed at about mid-way along the dorsal border. The rostrum is strongly down-curved and abruptly truncated at an angle acute to the dorsal border. Length : $4\frac{1}{2}$–$5\frac{1}{2}$ mm.

The above description is based on the following five specimens. The lectotype and syntype are from the Jones Collection, the remaining specimens from the Wright Collection, both now at the British Museum.

All specimens are from the Carboniferous Limestone of Little Island, Cork.

I. 6247.—Lectotype (here designated). Right valve. Pl. XI, Fig. 8 (Jones and Kirkby, 1874, pl. ii, fig. 30).

I. 6248.—Syntype. Right valve. Pl. XI, Fig. 5 (Jones and Kirkby, 1874, pl. ii, fig. 31).

I. 15741.—Left valve. Pl. XI, Fig. 7.

I. 15742.—Imperfect right valve (anterior obscured). Not figured. Length : *c.* 4·5 mm.

I. 15743.—Right valve. Pl. XI, Fig. 6.

Conclusion and Acknowledgments

The length of all figured specimens is noted in the explanation of the plate. Specimen numbers referred to are those of the British Museum (Natural History). The author would like to take this opportunity to thank the Museum authorities, and especially Mr. R. Baker, for their constant courtesy and help in making the museum specimens available. Certain expenses of the investigation were born by the University of Sheffield Research Fund.

References

Jones, T. R., and Kirkby, J. W., 1874. A monograph of the British Fossil Bivalved Entomostraca from the Carboniferous Formations. Part 1—The Cypridinadae and their Allies. *Palaeont. Soc.*, No. 1, pp. 1–56, pl. 1–5.

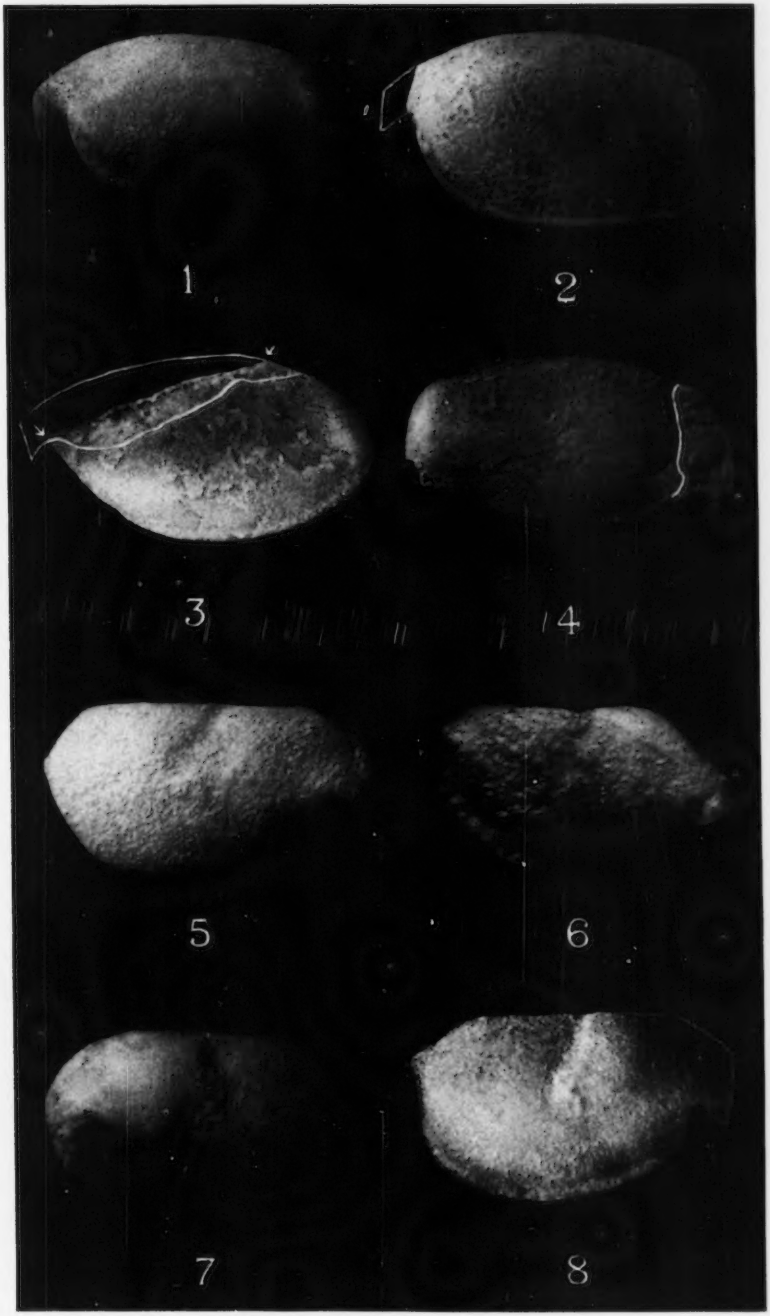
——, —— and G. S. Brady, 1884. Ibid., No. 2, pp. 57–92, pl. 6, 7.

Explanation of Plate XI

Figs. 1–4.—*Rhombina oblonga* (Jones and Kirkby). 1. An almost perfect left valve, showing muscle scar. × 6 (actual length, 7·2 mm.), B.M. No. I. 6269 ; 2. Left valve, the rostrum missing, × 6·2 (actual length, 7·3 mm.), B.M. No. I. 2547 (this is the holotype of " *R. belgica* " Jones and Kirkby) ; 3. Left valve. The rostrum and the whole of the portion above the white line has broken away. The gouge made by a needle and interpreted by Jones and Kirkby as the dorsal border is indicated between the two arrows, × 7·1 (actual length, 6·6 mm.), B.M. No. I. 6249 (this is the holotype of " *R. hibernica* " Jones and Kirkby) ; 4. Right valve (interpreted by Jones and Kirkby as a left valve). The portion anterior to the white line is obscured by matrix, × 6 (actual length from posterior to white line, 6·3 mm.), B.M. No. I. 6267 (this is the holotype of *R. oblonga*).

Figs. 5–8.—*Palaeophilomedes bairdiana* (Jones and Kirkby). 5. Right valve, × 9·8 (actual length, 4·7 mm.), B.M. No. I. 6248 ; 6. Right valve, × 7·9 (actual length, 5·3 mm.), B.M. No. I. 15743 ; 7. Left valve, × 7·9 (actual length, 5·3 mm.), B.M. No. I. 15741 ; 8. Right valve ; the rostrum is incomplete, × 8·6 (actual length, 5·1 mm.), B.M. No. I. 6247 (this is the lectotype).

All the specimens are from the Carboniferous Limestone of Little Island, Cork, Eire, except for Fig. 2, which is from Visé, Belgium. All the photographs are of the external lateral view and are by the author. Suggested reconstructions should be regarded as tentative.



CARBONIFEROUS OSTRACODA

New names for the Trilobite Genera *Menevia* Lake and *Psilocephalus* Salter

By C. J. STUBBLEFIELD [1]

ABSTRACT

Menevia and *Psilocephalus* are names in current use for two genera of Trilobites respectively occurring in the Middle Cambrian and Tremadoc rocks of Wales; both are now known to be invalid, having previously been used for other animals, and the new names *Meneviella* and *Psilocephalina* are proposed to replace them.

THE genus *Menevia*, which is a member of the Conocoryphidae, has had a singularly unfortunate nomenclatorial history; this has been partly summarized by Lake (1938, p. 270) when he proposed the name *Menevia* to replace the homonyms *Erinnys* Salter and *Salteria* Walcott; however, from the publication of Neave's *Nomenclator Zoologicus* (1939–1940) it emerges that the name *Menevia* itself is preoccupied; accordingly, the name *Meneviella* is now proposed as a replacement of the following three homonyms:—

(1) *Erinnys* Salter (1865 nomen nudum, p. 476; 1872, p. 177) *non* Agassiz (1846, p. 144).

(2) *Salteria* Walcott (1884, p. 31) *non* Wyville Thomson (1864, pl. vi, p. 1).

(3) *Menevia* Lake (1938, p. 270) *non* Schaus (1928, p. 665).

The type species of *Meneviella* is *Erinnys venulosa*, the original monotypic species of Salter's genus and the lectotype of that species is hereby chosen as the original of Salter (*in* Hicks) 1872, pl. vi, fig. 1, which was refigured by Lake, 1940, pl. xxxix, fig. 6, and is now preserved in the Sedgwick Museum, Cambridge. It came from the Menevian (Middle Cambrian) of Porth-y-rhaw, near St. David's, Pembrokeshire.

The generic name *Psilocephalus* Salter (1866*a*, p. 315, 1866*b*, p. 175) was given to the two species *P. innotatus* Salter 1866 and *P. inflatus* Salter 1866, of which *P. innotatus* had page priority in description and was subsequently designated the type species by Walcott (1924, p. 60). The generic name, however, had previously been assigned by Swainson (1839, pp. 194, 327) to a genus of fish. To replace the homonym *Psilocephalus* Salter (*non* Swainson 1839) the name *Psilocephalina* is now proposed, the type species being *Psilocephalus innotatus* Salter; the lectotype of that species is chosen as the specimen figured by Salter, 1866*a*, pl. vi, fig. 9 (1866*b*, pl. xx, fig. 14), and refigured by Lake, 1942, pl. xliv, fig. 2; this specimen, from the Tremadoc Slates occuring near Borth[-y-Gest], Merionethshire, is now preserved in the Sedgwick Museum, Cambridge.

[1] Submitted for publication with permission of the Director, Geological Survey and Museum.

REFERENCES

AGASSIZ, L., 1846. *Nomenclatoris Zoologici Index Universalis*, Soloduri.

LAKE, P., 1938. Monograph of the British Cambrian Trilobites, pt. xi. *Palaeont. Soc.*

—— 1942. Monograph of the British Cambrian Trilobites, pt. xiii. Ibid.

NEAVE, S. A., 1939–40. *Nomenclator Zoologicus* (4 vols.), London, Zoological Society.

SALTER, J. W., 1865*a*. On some additional fossils from the Lingula Flags, *Quart. J. Geol. Soc.*, xxi, 476–7.

—— 1866. Notes on the Sections and Fossils. *Rep. Brit. Assoc.* for 1865, p. 285.

—— 1866*a*. *In* Ramsay, A. C., The Geology of North Wales. *Mem. Geol. Surv.*, vol. iii, published in or before June, 1866.[1]

—— 1866*b*. A Monograph of British Trilobites, pt. iii. *Palaeont. Soc.*, vol. for 1864, published August, 1866.

—— 1872. *In* Hicks, H., On some undescribed Fossils from the Menevian Group. *Quart. J. Geol. Soc.*, xxviii, 177.

SCHAUS, W., 1928. *In* Seitz, A., *Die Gross-Schmetterlinge der Erde*, 6, p. 665, Stuttgart.

SWAINSON, W., 1839. *The Natural History of Fishes, Amphibia, and Reptiles or Monocardian Animals*, 2, pp. 194, 327, London.

WALCOTT, C. D., 1884. On the Cambrian Faunas of North America. *Bull. U.S. Geol. Surv.*, No. 10.

—— 1924. Cambrian and Lower Ozarkian Trilobites. *Smithson. Miscell. Coll.*, 75, No. 2.

WYVILLE THOMSON, P., 1864. Figures and Descriptions illustrative of British Organic Remains. *Decades Geol. Surv.*, xi, Trilobites, pl. vi.

[1] Mr. J. C. Harper has drawn my attention to " Donations to the Library of the Geological Society from 1st April to 30th June, 1866 ", *Quart. J. Geol. Soc.*, xxii, 1866, 610–639 ; here, on p. 638, is listed A. C. Ramsay's Memoir as being received, thus indicating that this publication predates part iii of Salter's Trilobite Monograph.

On a Discovery of Copper-Ore in the Torridonian Rocks of Sutherland

By Sir Lewis Leigh Fermor

Abstract

A description is given of nodules of copper-ore (ferruginous chalcocite) occurring in the Lower Torridonian rocks (Diabaig beds) at Clachtoll, N.W. of Lochinver, Sutherland.

At the Bay of Clachtoll, about 4½ miles N.W. of Lochinver, one can study the junction of the Torridonian beds of the Stoer Peninsula with the underlying Lewisian gneisses. But the principal point of interest for the present contribution is the occurrence of copper-ore in these Torridonian beds. Dr. Duncan M. Morison, of Edinburgh, had made this discovery some two years ago, but had not previously had the opportunity of having his find examined and confirmed by a geologist.

The copper-ore occurs in a small mass of Torridonian rocks dipping into the sea at a point about S.W. of the " C " of " Clachtoll " on Bartholomew's half-inch map, i.e. on the promontory separating the Bay of Clachtoll on the south from the Bay of Stoer on the north. On the one-inch Ordnance Survey map, Popular Edition, Scotland 15, Lochinver and Assynt, the site is just to the left (west) of the " C " of " Clachtoll ", and about 500 yards south of the ruined Pictish tower or " An Dun ", on the southern edge of the Bay of Stoer. The rocks composing the bluff are massive bedded sandstones overlying thinly-bedded sandstones, often ripple-marked, with sandy shales, the whole dipping to the W.N.W. at 25° to 30°. The general colour of the rocks is purplish-red. At the time of our examination I had with me no compass or foot-rule, so that the dips above and the measurements of thickness to be given below are all estimated.

The general estimated section is as follows :—

ft.	*in.*	*in.*	
12	0		Massive bedded sandstone.
3	0		Red sandy shales and thin sandstones, with a nodule of copper-ore 4 inches above the base.
2	0		Interbanded sandy shales and shaly sandstones, with nodules of copper-ore—details as follows :—
		4	Sandy shales with occasional nodules of copper-ore in top 1 inch.
		2	Shaly sandstone with copper-ore nodule.
		2	Sandy shale with occasional copper-ore nodule.
		10	Sandstone, with occasional copper-ore nodule in top.
		3	Sandy shale.
		3	Sandstone with copper-ore nodule at or in base.
		24	

ft.	*in.*	
	4	Shale.
	2	Sandstone.
3	0	Shales.
5	0	Ripple-marked and sun-cracked laminated sandstone with green copper stains, about 2 feet down.
		Massive sandstones.

The copper-ore forming the nodules is a black sulphide, thought in the field to be chalcocite, and usually with a green coating suggesting malachite. In places the nodules have decomposed in part so as to provide the material for green incrustations on bedding and joint planes of the containing rock. The nodules are usually found partially weathered out, often showing on the under surface of sandstone layers, or protruding from the edges of shaly layers.

The total thickness of rock through which the nodules were found is the 2 feet shown in the section detailed above plus the basal 4 inches of the overlying beds, making 28 inches in all. In addition, green copper stains were seen in the micaceous shales some 5 feet below the main copper zone.

The situation of the little headland or bluff in which the cupriferous zone occurs is such that there are no " backs ", and that at each end the copper-bearing bed dips into the sea. The total length of strike has not been measured, but it cannot be much more than some 150 feet.

The horizon at which the copper-ore occurs should, however, reappear to the N.N.E. on the northern side of the Bay of Stoer should there be no fault in between. Dr. Morison and I looked unsuccessfully for such a continuation, and after I had left Lochinver, Dr. Morison spent most of one day on another such search, but also without success. Should a continuation eventually be found then there is room for the ore bed to continue inland across the Stoer Peninsula. According to published geological maps, the beds in which this copper zone lies belong to the Diabaig or lowest of the three groups into which the Torridonian Series has been divided, and presumably to one of the sets of beds numbered 4 to 7 on p. 301 of the North-West Highland Memoir of 1907.

The nodules of copper-ore vary in size from that of a small pea to a length of over 1½ inches. The largest collected is flat, of irregular shape, with branches, and is 1·6 inches long, with a maximum width of 1·2 inches and a maximum thickness of about 0·3 inches. It has a thin crust of the sedimentary rock in which it was enclosed, and a specific gravity of 4·8 as taken with a Walker's balance. One branch was broken off during extraction and the fresh fracture thus caused shows a shiny black mineral with a black sectile streak and also scattered patches of a rich green mineral. The fattest nodule is spheroidal and nearly half an inch thick.

A few small specimens submitted to the Geological Survey and Museum were subjected to spectroscopic examination by Mr. C. O. Harvey, who reported "that they were probably ferruginous chalcocites". Mr. I. S. Loupekine, of the Department of Geology, University of Bristol, has since examined portions of one nodule by X-ray methods. He finds that the X-ray powder pattern of the black mineral is very similar to that of a mixture of hematite and Cornish chalcocite prepared by him for purposes of comparison. We must thus regard our nodules as composed mainly of a mixture of hematite and chalcocite, using the latter term in its older inclusive sense, without reference to whether the copper sulphide is orthorhombic chalcocite or the isometric chalcocite now termed digenite. Although a portion of the green copper mineral formed by the alteration of the chalcocite is probably malachite, much of it, judging from Mr. Loupekine's X-ray examination, is another mineral, the determination of which must be left to the future.

The discovery of copper ore in the Torridonian is of much interest, for it appears to be unique, except for a record of azurite found by Nicol [1] in the Torridonian sandstone in the south cliff of Quinag, also in Sutherland. He writes: "Higher up it is a dark, brownish-red, laminated rock, often containing large pebbles of quartz and a few traces of blue carbonate of copper."

This discovery is not mentioned in the North-West Highland Memoir, so that we must assume that the authors thereof did not meet with these incrustations. It is perhaps important to notice that the Torridonian rocks of Quinag are shown as belonging to the Applecross group and not to the Diabaig.

Origin of the Copper-Ore

The occurrence of copper-ore in a sedimentary stratum recalls at once the famous Permian *Kupfer-schiefer* or copper-bearing shales of Mansfeld, in Germany, where a cupriferous layer averaging 50 cm., or 2 feet, in thickness has been the locus of a mining industry for some 800 years, the ore containing 2 to 3 per cent of copper. The copper-ore contains several sulphide minerals minutely distributed through the shale, chalcocite being one of these sulphide minerals, but not the principal one. Opinions differ on the origin of the copper minerals of Mansfeld, whether they are to be regarded as syngenetic or epigenetic. On the whole the balance of opinion seems to favour the view that the copper is syngenetic.

Our Clachtoll deposit is of similar thickness to that of Mansfeld, but the sulphide mineral is segregated into nodules. If the copper mineral or minerals were originally deposited syngenetically and

[1] Nicol, J., 1857 *Quart. Journ. Geol. Soc.*, xiii, p. 24.

uniformly distributed they have since been rearranged and segregated into these ferruginous chalcocite nodules. Chalcocite is sometimes a primary mineral, but is more frequently of secondary formation resulting from the action of copper sulphate solutions on other sulphides. Whether at Clachtoll this segregation has taken place in such a way that the average tenor of the copper in the rock has remained roughly the same, or whether, as so often happens, the chalcocite represents a zone of secondary enrichment, which traced downwards will be found to become impoverished is, of course, unknown.

Also, as copper minerals have not been reported from other parts of the Torridonian of Scotland (except for the azurite of Quinag, which is in the higher Applecross group), we have no hint whether there was a period in Torridonian times when the conditions were such as to favour the deposition of copper salts from meteoric waters, or from decaying animal or vegetable matter. There is, however, no reason to attribute the presence of copper at Clachtoll to the action of intrusive rocks, as no local intrusions are exposed. There is a basic dyke to be seen on the shore to the west of Rudh an Dunain, cutting the pebbly grits of the Applecross group, but this is far away from Clachtoll and cuts a higher section of the Torridonians, separated from the Diabaig beds, according to the Survey Memoir, by an important fault. This dyke is presumably that marked as lamprophyre on the map accompanying the North-West Highland Memoir, but there appears to be no reference to this dyke in the text.

Economic Possibilities

It is possible to make a crude calculation of the average percentage of copper in the ore-bed in order to judge whether the occurrence is worth further investigation from the economic point of view. Making certain assumptions concerning the size and distribution of the nodules through the 28-in. section of strata given on a previous page, one finds that the content of copper would not be likely to exceed one-half per cent by weight if the nodules were pure chalcocite. As they contain a considerable but unknown proportion of hematite the amount of copper in the ore-bed must be considerably less than one-half per cent.

Although the economic possibilities of this discovery appear to be negligible, yet it would be interesting to find the continuation of this cupriferous bed on the Stoer Peninsula. There is one favourable point about this occurrence, namely that it would be very easy to separate the chalcocite nodules from their matrix by means of gravity.

CORRESPONDENCE

LINEATION IN HIGHLAND SCHISTS

SIRS,—In the January–February number of the *Geological Magazine* for the present year Dr. Coles Phillips publishes a letter in which he concludes that Dr. D. B. McIntyre has shown confirmatory evidence of speculations which he himself had made concerning the course of lineation south-east of the Great Glen.

While not denying this, I should like to call attention to a sentence which he quotes from an article by Dr. McIntyre in a previous number of the Magazine. "The direction of movement is clearly perpendicular to the lineation, and not parallel to it, as Hinxman assumed. The striping is a *b* lineation." If this statement had been put forward as a suggestion, no objection could perhaps have been raised. As it stands, however, it implies that the relation has been proved, and this is far from being the case.

After careful reading of all Dr. McIntyre's articles I am unable to see that any of them contains more than a suggestion. The only direct proofs so far published, as to the relation of lineation and movement, appear to me to be the following: (1) The evidence given by A. Kvale in 1945, in his paper "Petrofabric analysis of a quartzite from the Bergsdalen quadrangle" (*Norsk Geol. Tidssk.*, xxv, 193); and (2) the evidence derived from the elongation of pebbles in deformed conglomerates. In the first case the conclusion seems to be open to no challenge whatever that the lineation and the direction of movement are parallel.

In Scotland there are unfortunately no cases of deformed conglomerates occurring in conjunction with lineation, such as might prove either case. In the paper which I read to the Geological Society in 1948, however, "On lineation and petrofabric structure, and the shearing movement by which they have been produced" (*Quart. Journ. Geol. Soc.*, civ, 99), I mentioned two instances from the Erzgebirge and one from New Hampshire, in all of which the greatest elongation is parallel and not perpendicular to the lineation.

Dr. Phillips must be aware of these cases and cannot assume that all lineation is in the *b* direction, and transverse to the direction of shear. More probably he supposes that in different circumstances an *a* or a *b* lineation may result. This opinion was expressed by more than one speaker in the discussion which followed my 1948 paper. The character of the "simple shear" which produces the two types had been very carefully defined and cannot explain the difference. The same physical cause must, therefore, one must suppose, give rise to very different results. That both an *a* and a *b* lineation can be produced by it appears to me to be an absolute impossibility.

E. M. ANDERSON.

62 GREENBANK CRESCENT,
EDINBURGH.
16th April, 1951.

ATLANTIC CLIFFS

SIR,—In his recent paper entitled "Atlantic Gulfs, Estuaries, and Cliffs" (*Geol. Mag.*, lxxxviii, 1951, pp. 113–128), Professor C. A. Cotton discusses my views on the bevelled cliffs of Cornwall (M. A. Arber, "Cliff Profiles of Devon and Cornwall," *Geogr. Journ.*, cxiv, 1949, 191–7). He says (p. 125), "The upper part (since graded back to a much gentler slope by subaerial process) once, apparently, descended, steeply no doubt, to a raised beach of interglacial or interstadial age (M. A. Arber, 1949, p. 196). It has been reattacked and steepened (freshened) at the base since the last return of the sea. This is essentially the explanation adopted by Miss Arber (1949), though her recognition of a changeover from marine cliff-cutting to subaerial erosion during glacial-age marine regression is not explicitly stated."

Professor Cotton goes on to say that Challinor (*Geol. Mag.*, lxviii, 1931, 111–121 ; *Geography*, xxxiii, 1948, 27–31 ; *Geography*, xxxiv, 1949, 212–15), " on the other hand, explains the bevel or upper cliff quite differently."

I wish to say that I have never held the view which Professor Cotton attributes to me (although he admits that I have never " explicitly stated " it) ; and that I agree with Mr. Challinor's interpretation of a bevelled cliff : that the curve above is due to subaerial erosion proceeding *pari passu* with the marine erosion which cuts the vertical face below.

As I have tried to show in my paper on the cliff profiles, the distribution of bevelled cliffs in Cornwall is a consequence of the structure, especially jointing, of certain rocks. I believe, as I there suggested, that the wave-cut face, as well as the bevel above, was probably cut before the end of the Riss glacial period (or whatever date the raised beach was cut), and therefore I should not subscribe to a " hypothesis of two-cycle origin " such as Professor Cotton suggests for the present cliff profiles.

Professor Cotton (p. 126) also refers to the view expressed by E. A. N. Arber, Dewey, Macar, and myself, that the " truncation of the valleys of some small streams by cliff retreat . . . might be cited as proof of exceptionally rapid recession of the cliffs ". Professor Cotton then says that " such a theory is inconsistent with the fact of preservation at various places of a raised beach covered by head presumably of glacial age ". From my own observation, I can however say that where the valleys are most truncated and the coastal waterfalls highest, in the coast south of Hartland Point, there are (so far as I know) now no remains of the raised beach. That where the valleys are truncated, the raised beach (if it ever existed) has been destroyed, is further evidence of the rapidity of recession of the cliffs.

MURIEL A. ARBER.

52 HUNTINGDON ROAD,
CAMBRIDGE.
27th April, 1951.

REVIEWS

RÉPUBLIQUE SYRIEN : CARTE GÉOLOGIQUE AU 50,000, FEUILLE DE ZEBDANI. (Damascus, Ministère des Travaux Publics, 1949.)
RÉPUBLIQUE LIBANAISE : CARTE GÉOLOGIQUE AU 50,000, FEUILLE DE DJEZZINE, 1950 ; FEUILLE DE RAYAK, 1950 ; CARTE GÉOLOGIQUE AU 200,000, FEUILLE DE TRIPOLI, 1949. (Beyrouth, Ministère des Travaux Publics.) By L. DUBERTRET.

The splendid geological maps of Syria and Lebanon on the 1 : 1,000,000 scale and of the Middle East on the 1 : 2,000,000 scale, by M. Dubertret, are well known. He and the two republics are to be congratulated on this series of new geological handbooks. Their size is right for the pocket, yet each contains a folding coloured geological sheet, from eight to twelve full-page photographs, a bibliography, and on the average sixty-three pages of text with many diagrams, sketch-maps, and sections. Each is an admirably clear, self-contained account of the stratigraphy (Jurassic to Pleistocene), geomorphology, and tectonics of the area and its broader setting. If two small criticisms are not ungracious, they are that one looks in vain for a statement of what other sheets have been published or are in preparation, and that all the stratigraphical tables are upside down. The Zebdani sheet covers part of the classic area of Mount Hermon and includes two pages of photographs of Palaeolithic implements.

W. J. A.

LAS ROCAS ERUPTIVAS AL MICROSCOPIA : SU SISTEMATICA Y SU NOMENCLATURA. By MARIO E. TERUGGI. Instituto Nacional de Investigacion de las Ciencias Naturales : Publicaciones de Extension Cultural y Didactica, No. 5. pp. 398, text figs. 79. Buenos Aires, 1950.

The author, in his preface, deplores the multiplication of rock names and the lack of an agreed system of classification and nomenclature ; nevertheless he has prepared this book in the hope of assisting Spanish-speaking students who may come upon these deplorable names in the course of their reading. In the very complete index he includes about 1,400 names of all kinds. If we omit compound names, purely textural names, and duplicate spellings (e.g. bekinkinita and bequinquinita, kyschtymita and quishtimita) there remain some 590 single-word names of the familiar geographical or mineralogical character. The system of classification followed, for which no originality is claimed, is mineralogical and to a small extent quantitative. The fundamental criterion is the degree of saturation with silica. Other factors recognized are the composition of the feldspar and the ratio of feldspar to feldspathoid. The resulting grand groups are termed clans ; of these there are 19, each containing plutonic, volcanic, and dyke rocks. The dyke rocks are described as aschistic or diaschistic and leucocratic, mesocratic, or melanocratic.

The book is admirably printed on good paper and illustrated by text-figures drawn from thin sections ; some of these are borrowed from Harker or Johannsen but the majority are original and all are commendably clear. The author is to be congratulated on a book which will be of great assistance to all Spanish speaking geologists.

S. J. S.

SURVEY OF EGYPT : SURVEY DEPARTMENT PAPERS. No. 49, THE EGYPTIAN DESERT AND ITS ANTIQUITY ; No. 50, THE SURVEY OF EGYPT, 1898–1948. By G. W. MURRAY. Cairo, 1950.

From 1932–37 Mr. G. W. Murray was Director of the Desert Survey and from 1937–47 Director of the Topographical Survey of Egypt. No one could produce a more authoritative account of the history and work of the first half-century of the Survey. It is a fascinating story. " Besides the normal functions of a Survey Department, almost all scientific work in Egypt connected with measurement was either initiated or reorganized during the first decade of the present century by Captain Lyons." There are short chapters on the Cadastral, Desert, Topographical, Geodetic, and Geological Surveys, and a complete bibliography of their publications. It is to be hoped that there will be many British and Egyptian readers of the achievements of this enterprising band of scientists who devoted their lives to the service of Egypt and to the exploration of the deserts. After Sir Henry Lyons came John Ball, G. W. Murray himself, P. A. Clayton, G. F. Walpole, H. J. L. Beadnell, W. F. Hume, O. H. Little, and many others. Before mapping of the deserts could begin the first task in 1898 was to survey over 2,500,000 small holdings in ten years, as the basis for land tax. Until then the method of computing areas had been in use since Pharaonic times and produced errors sometimes of up to 41 per cent. The chapters that will first attract geologists, however, are those on the Desert Survey and the Geological Survey. The latter began in 1896 and was transferred in 1945 to the Department of Mines. Murray expects that after another fifty years there will be no more of Egypt left unmapped. " Let us hope, too, that fifty years hence the founders of the Survey will not have been quite forgotten."

Paper 49, on the age of the Egyptian deserts, is the first thorough review of a wide variety of evidence—geological, hydrographical, botanical, archaeological—by one who is an authority on all of them and an acute and lifelong observer. It is a work that should not be missed by geologists or prehistoric archaeologists, and it can be recommended as of intense interest to all concerned with deserts and with geologically recent changes of climate.

W. J. A.

A Revision of Fossil Sequoia and Taxodium in Western North America Based on the Recent Discovery of Metasequoia. By Ralph W. Chaney. Trans. American Philosophical Society, N.S., Vol. 40, Pt. 3. Philadelphia, 1951. $1·50.

This is an important revision of the fossil redwoods and swamp cypresses of North America, illustrated by photographs of fossil and living material. *Sequoia*-like foliage is abundant in many North American Tertiary floras, but the numerous species hitherto described have given a good deal of difficulty, largely because an unsuspected third genus was present in addition to *Sequoia* and *Taxodium*, all three having very similar leaves.

Lesquereux first pointed out that some of these species were associated with peculiar cones borne on slender stalks, but it was only some ten years ago that these cones were realized to differ sufficiently from those of *Sequoia* to warrant the creation of a new genus, *Metasequoia*. About this time, there were stories of a large undescribed conifer growing in the interior of China and when, a few years ago, these rumours were confirmed, the living trees were found to be bearing *Metasequoia* cones, together with foliage like that associated with the Tertiary cones. This surviving species, *M. glyptostroboides*, has now been studied in detail, and it is claimed that fossil *Metasequoia* foliage can be distinguished with certainty from that of *Sequoia* and *Taxodium*. A critical revision of the fossil species of these three genera results in the disappearance of several European species, such as *S. langsdorfi*, from the American flora, and shows that probably no more than five species in all are present in the Cretaceous and Tertiary of North America. It now appears that the foliage of *Metasequoia* is more abundant than that of any other conifer in the Lower Tertiary rocks of western North America, but there are no records from rocks younger than Miocene in this region. In Japan the genus survived into the Pliocene, and a few trees are still living in the remote interior of China.

M. B.

The Geology of the Commonwealth of Australia. By the late Sir T. W. Edgeworth David, edited and much supplemented by W. R. Browne. London: Edward Arnold, 1950. 3 vols. Vol. I, Historical Geology, xx + 747 pages; Vol. II, Physiography and Economic Geology, iv + 618 pages; Vol. III, box containing Geological Map of the Commonwealth of Australia, 1 : 2,990,000, and Geological Sketch-map of Australian New Guinea, 1 : 2,500,000. £12 12*s*. (Volumes not sold separately.)

The plan of writing a book on the geology of Australia seems to have been already in Sir Edgeworth David's mind before his academic work was interrupted by the outbreak of war in 1914. On his return to Australia, work on the project was undertaken as opportunity offered, but it was not until he retired from the Chair of Geology at Sydney that he was able to devote most of his time to the assembling of material for the book and the map which was to accompany it.

The map was completed first and was published in 1932, together with a slender volume of explanatory notes, which gave a summary of Australian geology as it was then known. By this time an enormous amount of material for the text had been assembled from the rather scattered literature, and a few chapters were near completion; but the 'thirties were active and fruitful years for Australian geology, and new results, leading to changed interpretations, were steadily pouring in, so that by the time of David's death in 1934 much of his manuscript already needed revision.

At this stage Dr. Browne took over the task of completing the book, and one can have nothing but admiration for the results of his labours. In spite of the vast amount of information gathered together in its two large volumes of text, the book is surprisingly easy reading, and Dr. Browne's lucid style enables him to present a series of vividly clear pictures of Australian geology.

The first volume is devoted to historical or stratigraphical geology. The Commonwealth of Australia preserves a remarkably continuous record of its geological history, inasmuch as almost all the systems are represented within its borders from the older pre-Cambrian through to Pleistocene and recent strata. It preserves the remains of three major glaciations, those of the late pre-Cambrian and late Palaeozoic showing proof of much greater severity than that of the Pleistocene ; evidence for a Cretaceous glaciation is also presented, by no means so convincing as that of the others. The stratigraphical development of each system is described state by state in considerable detail, followed by discussions of more general topics, such as fossils, correlation, and palaeogeography. The final chapter gives an outline of the palaeogeographical history of the Australasian region, which is particularly useful to overseas readers. This section of the book is a mine of well-ordered information, and further comment would be superfluous.

The first chapter in Part II of the book contains an excellent summary of Australian physiography, condensed into less than thirty pages, and it is to this chapter that the reader will turn for a comprehensive view of the subject. The following chapters deal with the physiography of the individual states, an arrangement which cuts across natural boundaries and detracts something from the usefulness of these chapters. Australia has no high mountains comparable with the Tertiary chains of other continents, for the Tertiary folds miss the Australian mainland and come no nearer than the girdle of island arcs. The Mesozoic and Tertiary strata, as a consequence, are practically horizontal, and the upland regions of Australia are more or less obviously dissected peneplains or plateaux. The evolution of the present surface by the successive development and dissection of a whole series of peneplains during Tertiary times is brought out very forcibly, as is also the remarkable state of preservation of some of the older surfaces. Perhaps the most impressive of all is the Miocene surface, which still retains its mantle of lateritic soil over large areas. The short chapter on soils reveals an interesting state of affairs, in that some other mature soils, such as the black earths, are not everywhere in harmony with local soil-forming processes, and must have been formed under climatic conditions different from those now prevailing. There must be few parts of the world where ancient soils can contribute so much to the understanding of physiographical history, and it may be hoped that David and Browne's review will stimulate more research along these lines.

Economic Geology is the subject of Part III. The chapter on gold makes fascinating reading, and is followed by accounts of the other metals. Australia has contributed substantially to the world's output not only of silver, lead, zinc, copper, and tin, but also of tantalum, titanium, osmiridium, and zirconium ; these rarer elements being won almost entirely from detrital concentrates of heavy minerals. As the authors point out, however, coal mining is one of the Commonwealth's most important mineral industries, and the next hundred pages are devoted to the coals of the several states. The earliest coals are of Permian age, and there are workable coals or lignites in all the following systems up into the Tertiary, when the climate became at last unsuitable for peat accumulation. The Permian coals are mostly bituminous, with some steam coal and anthracite in Queensland, and much of the Mesozoic coal has a moderately high fuel ratio. The most remarkable of the very varied deposits in the Commonwealth must be the Tertiary lignites of Gippsland, in which three seams together exceed 1,000 feet of coal, with a very small thickness of interstratified measures. The oil shales are dealt with in a short but interesting chapter. The kerosene shales, like the Scottish torbanites, are algal deposits, the richest of which give more than 230 gallons of crude oil per ton, capable of yielding 66 per cent of refined petrol in a modern cracking plant. Australia thus possesses a handsome reserve of petroleum which will doubtless come into its own when production elsewhere from liquid oil offers less competition. The search for liquid oil in the Commonwealth has so far proved disappointing.

Artesian water is the last of the important subjects dealt with in the book. The water of the Great Australian Basin is now regarded as entering the aquifers from an extensive belt of intake-beds in Queensland and New South Wales. The character of the waters and of their dissolved gases and solids is fully discussed, and an illuminating sketch-map shows the observed directions of migration underground. In some of the younger artesian basins there is a notable departure from normal artesian conditions in that there is no confining impervious layer above the aquifer, the hydraulic pressure of the water apparently being balanced by friction.

The bibliographies are placed at the end of each chapter, but there are practically no references to literature in the body of the text. This may not matter much to an Australian reader, but presents an unnecessary obstacle to others who may wish to go to original sources. The price is substantial, and many who would wish to buy a single volume will find the whole work beyond their means ; it is very much to be hoped that in a future edition the volumes may be sold separately.

M. B.

PETROLEUM GEOLOGY. By E. N. TIRATSOO. Methuen, 1951. xix + 449 pp., with 122 text-maps and diagrams, 8 plates, and 2 folders. 42*s*. net.

The prime requisite for a petroleum geologist, as for any other geologist, is a sound academic training in pure geology. Formerly the more specialized knowledge needed by the industry could be acquired by working experience, but nowadays some assistance is necessary. Dr. Tiratsoo is to be congratulated on producing such assistance, in the form of the first British book of convenient size which briefly reviews the main interests of the profession, and which also provides an abundance of references (over 1,000 of them) to encourage delving in the literature. Primarily designed for the needs of Honours Students at the Royal School of Mines, the book will be a valuable aid to students without the advantage of specialized training. It can be divided into three sections ; four chapters dealing with the theoretical side of oil formation and accumulation ; six chapters giving a brief description of the geology of the world's oilfields ; and six chapters describing the modern techniques used in oil exploration and exploitation. The theoretical section is a readable and excellent summary of a subject on which, all things considered, there is a remarkable agreement on the main essentials, largely based on the experience of hundreds of thousands of bore-holes. When it comes to details, however, there are still important differences of opinion. The section on techniques is also a most useful and readable summary ; the minor criticism could be made that some of the material included in the chapter on correlation is adequately dealt with in normal geological textbooks, but this is a small detail. The descriptive section on the world's oilfields is a valiant attempt at compression. It might, however, have been better to have given an even briefer review of the whole, with an expanded description of carefully selected oilfields to illustrate interesting examples of the main types of accumulation. The treatment given leads to some lack of proportion, Scotland, for example, getting the same amount of space as Kuwait. It is a pity that so many of the maps and sections lack scales, but this is perhaps less important in a textbook than in practice. The reviewer found a few minor errors and a few misprints, but in general the book is well turned out and pleasant to look at, and can be recommended. The price at first sight may seem high, but a little reflection will surely lead to the conclusion that the lists of references alone are really good value at two guineas, so a purchaser should have no regrets.

N. L. F.

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